THE USE OF A RESPONSE SURFACE DESIGN IN THE AGRONOMIC EVALUATION OF A GRASS-LEGUME MIXTURE UNDER GRAZING

By

EMANUEL ADILSON SOUZA SERRÃO

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1976

DEDICATED TO MY PARENTS,

MY WIFE, CHRISTINE,

AND MY DAUGHTER, LEANDRA

ACKNOWLEDGMENTS

The author wishes to offer his most heartfelt gratitude and devotion to Almighty God for granting him the physical and mental powers to see him through all phases of his academic career and for bringing him safely to this new plateau of learning.

Sincere and special thanks and appreciation are due to Dr. Gerald O. Mott, Professor of Agronomy and Chairman of the Supervisory Committee, for his invaluable and continuous guidance, advice and assistance throughout the author's academic program at the University of Florida.

The author's appreciation is extended to Dr. John E. Moore, Professor of Animal Nutrition; Dr. Larry D. White, Associate Professor of Range Management; and Dr. Hugh L. Popenoe, Professor of Soil Science, and Dr. Ramon C. Littel, Associate Professor of Statics, all members of the Supervisory Committee, for their continual willingness in providing the author their professional assistance whenever needed and for their valuable comments and suggestions during the preparation of this document. Special appreciation is due to Dr. Frank G. Martin, Professor of Statistics, for his outstanding contribution in the statistical analysis of the results of this research.

For their help during the field work of this research, the author wishes to thank Mr. Fred McKay and Mr. Michael Paulick, Agronomy Department technicians. Appreciation is also due to the technicians of the Agronomy Department Forage Laboratory, especially Miss Janet M. Ferguson and Mrs. Edwina L. Williams, for their assistance in the laboratory phase of this research.

The author also wishes to acknowledge members of the staff, secretaries, and fellow graduate students in the Agronomy Department who, in some way, contributed to the completion of this dissertation. Dr. William R. Ocumpaugh is acknowledged for his assistance during and after the field phase of this research.

The author wishes to thank Mrs. Ann Barry for typing the final copy of this manuscript.

Special appreciation is due to the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) of the Brazilian Ministry of Agriculture, for providing the author the opportunity to obtain this graduate training which is now near completion with the presentation of this manuscript.

A special word of thanks is offered to both Dr. and Mrs. Gerald O. Mott for the warm friendship and generosity they extended to the author and his family throughout their stay in Gainesville.

Finally, the author lovingly acknowledges his dear wife, Christine, and his daughter, Leandra, for the love and devotion they have never failed to give and for his wife's encouragement, patience, and her invaluable assistance in editing and typing during the preparation of this dissertation.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

Figure		Page

Abstract of Dissertation Presented to the Graduate Council
of the University of Florida in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

THE USE OF A RESPONSE SURFACE DESIGN
IN THE AGRONOMIC EVALUATION OF A GRASS-LEGUME
MIXTURE UNDER GRAZING

By

Emanuel Adilson Souza Serrão

December, 1976

Chairman: Dr. Gerald O. Mott
Major Department: Agronomy

A grass-legume pasture composed primarily of Coastcross-1 bermudagrass (<u>Cynodon dactylon</u> (L.), Pers.) and Greenleaf desmodium (<u>Desmodium intortum</u> (Mill) Urb.) was evaluated in a grazing trial during 182 days in the growing season of 1975 at the Beef Research Unit, University of Florida, Gainesville. The pasture was established in 1974 on a soil of the Sparr series associated with the Blanton series.

The main objectives of the study were (a) to determine the effect of grazing period (X_1), rest period (X_2), and grazing pressure (X_3) upon the pasture mixture, (b) to evaluate a response surface design for the statistical analysis of the experiment, and (c) to evaluate the forage residual dry matter as an estimator of grazing pressure.

Grazing periods studied were 1, 3.5, 7, 10.5, and 14 days; rest periods were 0, 14, 28, 42, and 56 days; and projected grazing pressures were .5, 1.0, 1.5, 2.0, and 2.5 metric tons/ha of dry matter (DM) left after grazing.

In order to cover the five planes of the complete factorial, a

modified non-rotatable Central Composite Design made up of eight factorial, six axial, one central, and five extra treatments was used to study the response surface of the individual response variables.

The experimental error was obtained from five replications of the central treatment (7 days grazing, 28 days rest, and 1.5 metric tons of residual DM), which would be expected to be close to the optimum compromise between the pasture and animal potentials.

The response variables included parameters of pasture production and yield (total DM available per cycle; growth rate; net dry matter; DM on offer per 100 kg body weight; stocking rate; and DM consumption), botanical composition (percentage of physiologically active grass, desmodium, and weed; percentage of litter), and forage quality (physiologically active grass *in vitro* organic matter digestion (IVOMD) and crude protein (CP); litter IVOMD; and animal performance).

A double-sampling procedure was used for estimating parameters of pasture production and botanical composition. Indirect measurements made visually and with a forage meter were compared with measurements of actually harvested samples. Regression coefficients were then obtained and used to adjust additional indirect measurements.

Each response variable was satisfactorily approximated in the general region of the experimental variables by a second-order model of the type $\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$. The response surface of each response variable was analyzed in detail using the concepts of Stationary Point and Canonical Analysis, along with interpolations within the region of the experimental variables.

In general, rest period and grazing pressure had predominant influences on the nature of the response surface of all response variables,

but, in most cases, grazing period had a complementary effect. Their influences are discussed in detail, together with predicted points and respective responses along the paths of steepest ascent and descent.

The modified non-rotatable Central Composite Design proved to be a very useful statistical tool in the grazing experiment, not only for reducing considerably the number of treatments needed to study the whole response surface, but also because it allowed for modification of the basic design and for the addition of extra treatments of interest. The use of the concepts of Stationary Point and Canonical Analysis, illustrated with contours of equal response, was very useful in the interpretation of the relationship between grazing period, rest period, grazing pressure and the response variables, besides aiding in predicting their combination, which results in optimum, maximum or minimum responses, and information for further experimentation.

Visually estimated residual DM left after grazing was found to be a very satisfactory estimator of grazing pressure in grazing experiments and can be applied in practice. However, periodic double sampling is necessary and it will often require the put-and-take technique.

INTRODUCTION

Animal protein has been and will always be a major factor in human nutrition. The production of such an important commodity has been, in the last decade, one of the primary concerns of plant and animal scientists on whose research rests the responsibility of meeting the demand for food of our world's increasing population.

In most developed countries of the world where research has generated high levels of technology, intensive systems of animal protein production have had the contribution of both native or improved pastures and other crops such as grains and conserved forages. These systems have required high levels of energy inputs. Where the pasture is the main source of the animal's nutritional requirements, high levels of fertilizers and/or high forage-producing legumes are generally a part of the system.

In less developed areas, primarily in the tropics, animal protein production is still an extensive operation based primarily on native grasslands and, to a much lesser extent, on improved grasslands where inputs of fertilizers and/or forage legumes are still far from being a reality. This system yields low quantities of animal products per unit area of land.

The recent energy crisis in the western hemisphere has caused major increases in the cost of producing fertilizers and other farm inputs, resulting in large increases in the cost of producing grains

which have been used for human consumption and as animal feed. Due to that fact and man's growing need for food, it does not seem possible to continue diverting grains for animal consumption in the years to come.

These facts emphasize the importance of forages as the main, if not the only, source of feed to meet the animal's requirements for production. This trend is apparent in highly developed countries such as the United States of America, and will certainly be the system to be continued in less developed tropical areas of the world.

In order to realize high animal product outputs per unit area of land from forages, either as pasture, green chop, conserved feed or from their combination, more intensive cultural and managerial practices will be necessary.

If improved pastures are to be used as the main or sole source of feed, and if high outputs of animal products are expected, it will be necessary to utilize high quality forages, not only those with high yield potential, but those which will perform efficiently under appropriate grazing management systems. Such efficient systems will demand more intensive management of the soil-plant-animal complex. Among other farm inputs, fertilizers will have to play an important role for the increase and maintainance of forage production, and, most probably, nitrogen fertilizer will be the main limiting factor in maintaining the productivity of the system.

Most tropical and subtropical areas of the world have been endowed with forage grasses of high yield potential which, in many areas, can produce forage during the entire year, although their quality may be inferior to that of temperate grasses. This deficiency may be overcome, however, if adequate management is used.

The recent scarcity of nitrogen fertilizers, the high energy requirement of their manufacture and, most significantly, their increased market prices have made the use of atmospheric nitrogen-fixing plants in the system even more important. This is particularly true for the less developed countries of the tropics where prices of nitrogen fertilizers are prohibitive. Recent scientific developments indicate that an unknown number of tropical forage grasses are capable of fixing significant amounts of atmospheric nitrogen which will certainly be a factor contributing to increased forage grass yields. However, the well-known symbiosis between legumes and bacteria of the genus *Rhizobium* will probably be the major vehicle for introducing free nitrogen into the soil-plant-animal system. The tropical environment propitiates the existence of an abundance of these legumes.

In spite of this abundance of forage legume germplasm, these plants have, up to the present, played a minor role in livestock production in the tropics. Some legumes which have been evaluated for forage production have been discarded in view of their lack of persistance in pure stands or in grass-legume mixtures. Most of these evaluations have been made in small-plot experiments under mechanical clipping conditions in which the defoliation has a very different effect from that resulting from the grazing animal. Sometimes, the legume's nutritional requirements in the mixture are satisfied, but the defoliation management is inadequate, resulting in negative effects on the regrowth mechanism and a consequent predominance of the companion grass.

It is clear then that, in the intermediate phase of the logistics sequence of evaluating forages for grazing purposes, principally for

grass-legume mixtures, the use of agronomic experiments, in which grazing animals are used instead of the mowing machine, are a must. In these experiments, the main purpose is to determine the effect of the grazing animal on the pasture.

In the tropics and subtropics, there are many factors, especially grass-legume mistures, which need to be studied in evaluating forages under grazing. Therefore, the use of exploratory statistical designs which will allow the evaluation of the response of the pasture to a broad spectrum of management factors with a minimum of resources and facilities needs to be given urgent consideration. Consideration also needs to be given to new methods of measuring quantitative and qualitative pasture responses in grazing experiments. These sampling techniques should be inexpensive, reliable and expeditious.

In the context of grazing management, length of grazing period, duration of rest period, and grazing pressure are the three most important factors. In a grass-legume mixture, it is very important to know the independent effects as well as the interactions among these factors. The response of a species in a single-species pasture and the dynamics of the equilibrium between species in mixed pastures should be known if appropriate recommendations are to be made under various alternatives of grazing management.

In grazing experiments, length of grazing period and length of rest period are experimental variables which can be imposed without error or subjectivity. However, grazing pressure, which is the amount of forage available per animal, is generally imposed as Animal Days/ Unit Area, Liveweight/Unit Area, or Dry Matter on Offer/Animal/Day. These estimators of grazing pressure, besides being subjective, are measured with error associated with the pasture and the animal varia-

tions. Consequently, it is necessary to develop alternative estimators of grazing pressure which will eliminate one or more sources of variation in order to attain more accurate measurements of plant and animal parameters being studied, and which can be more directly applied in practice.

This research was conducted with the purpose of:

1. determining the response of a pasture grass-legume mixture to various treatment combinations of the grazing management factors length of grazing period, length of rest period, and grazing pressure;
2. determining the feasibility of using the residual dry matter left after grazing as an estimator of grazing pressure;
3. studying the possibility of using a Response Surface Design in agronomic experiments for forage evaluation under grazing; and
4. generating coefficients from the response surface for plant and animal responses which will be useful in developing forage-livestock feeding systems.

REVIEW OF LITERATURE

Logistics in Evaluating Forages and Pastures

Research in pasture and forage evaluation has progressed considerably during the past 4 decades, and this rapid progress, which comprises both plant and animal studies, has brought about significant advances in understanding the bases for high levels of forage and pasture production both in tropical and temperate regions. As a result, a wide variety of techniques has been developed to evaluate forages and pastures. However, if techniques for forage and pasture evaluation are to be relevant to plant-animal systems--whether they be physical, chemical, ecological or nutritional in nature--they should be in some way related to output per animal or output of animal product per unit area (Mott and Moore, 1970).

The pasture-animal system is so complex that it is always difficult to study its underlying mechanisms. For this reason, Humphreys (1966) stated that "the management of veld is an art, which can only be guided by scientific finding." In order to obtain maximum information from a forage evaluation program, a multidisciplinary effort is necessary.

Even though standardization for forage and pasture evaluation techniques is obviously impossible, attempts should be made to develop research investigation programs which would involve plant and animal nutrition, breeding, physiology, pathology, and ecology, as well as climatology, soils, statistics, economics, and other disciplines.

Unfortunately, such an ideal research team is not feasible in most situations. A few tentative schemes for the logistics of pasture and forage evaluation have been suggested (Mott and Moore, 1970; Myers et al., 1974) which would involve as many specialists as possible.

In the scheme suggested by Mott and Moore (1970), the plant breeder, the agronomist, the forage physiologist, the soil fertility specialist, and the animal nutritionist play important roles. The scheme attempts to indicate the various steps from the agronomic evaluation sequence for forages to the point where the response by the animal is measured and, ultimately, systems of feeding are developed. Their scheme is a sequence which begins with the use of introduced forage plants or with local breeder's lines. These plant materials go through a screening sequence involving small-plot clipping studies, uniformity tests, environmental evaluation, clipping management and fertility studies, agronomic evaluation under grazing (mob grazing), animal response experiments in terms of product per animal and animal product per unit area, and, finally, the use of the screened forage(s) in forage-livestock systems. Most phases of the scheme are accompanied by quality evaluations of the forage(s) by in vitro or in vivo methods.

A more detailed scheme is suggested by Myers et al. (1974). Their scheme, as in that of Mott and Moore (1970), is intended to make the best use of the restricted seed supply usually available of new introductions or local lines of pasture plants, to efficiently reduce their number to manageable proportions, to ensure assessment of seasonal variation of performance without prolonging testing unduly, and to form a consolidated record of performance of the screened material.

The summary of the authors scheme is as follows:

Stage 1A: Nursery rows.

Stage 1B: Second year nursery rows.

Stage 2A: Grass-legume swards.

Stage 2B: Crass-nitrogen swards (attention to 2A).

Stage 3: Grazing trial.

The authors indicated the plant and the animal records to be taken in each stage and pointed out the flexibility of the scheme for different circumstances. Again, the team-work approach is implicitly present.

Small-Plot vs Grazing Experiments

Undoubtedly, the majority of the research work on forage evaluation reported in the literature relates to agronomic experiments which do not include grazing animals. There are many fundamental problems of establishment and maintenance of forages which may be solved without the use of animals, whereas other problems may be best and frequently only solved with the use of the grazing animal.

Small-plots are extremely valuable as a means of obtaining certain basic information on the soil, climatic and management requirements of forages.

According to Chamblee (1962), in forage and pasture evaluation, the problems to be faced generally fall into three categories: (1) those largely independent of the effect of the animals, (2) those in which the investigator needs to determine the influence of the animal on the sward but does not necessarily need to determine the effect of the sward on the animal, and (3) those which can be solved only by evaluation with the animal. Generally, the first two types of problems are studied in relatively small plots, whereas the third type needs relatively large pastures.

In both clipping and grazing experiments, the term defoliation is often employed to imply removal of plant shoots. Defoliation may be categorized in terms of its frequency or time interval between defoliations. Intensity of defoliation is measured by the proportion of the plant removed and the amount and characteristics of the remaining material after defoliation; time of defoliation may be considered in relation to the developmental stage of the plant or plants, the tiller population and its age, the carbohydrate status of the plant, and the nature of current environmental conditions (Humphreys, 1966).

The dangers of extrapolation of results from clipping experiments to grazing practice have more recently been given increased consideration by conscientious pasture scientists. Even though both forage yield and quality are readily influenced by grazing and cutting practices, cutting and grazing affect the response in different magnitudes. Blaser (1966) demonstrated that, in general, yields of grazed swards are lower than those of the same swards under clipping conditions.

Chamblee (1962) indicated that, in clipping trials, many investigators attempt to simulate grazing with a mowing machine or similar mechanical means and that much information on the effect of different intensities of defoliation and other management variables may be achieved by this method. However, he warned that the "investigator must be extremely careful in choosing the mechanical means for harvesting and even more so in the interpretation of the data." Blaser (1966) and Chamblee (1962) agreed that trampling, biting off of the forage (generally in a selective fashion), the feces and urine, and soil compaction account for most of the differences between grazed

and clipped pastures and that data obtained by simulated grazing with the mowing machine often cannot be applied directly to grazing conditions. Hodgson (1974) pointed out the shortage of information on the production and utilization of herbage under grazing and of direct comparisons of cutting and grazing. He indicated, however, that methods of avoiding the supposedly adverse effects of the grazing animal on the sward have had no measurable effect on the output of animal products per head or unit area.

In few cases, the evidence does not support the general rule that clipping gives higher yields than grazing. For example, in Kenya, Keya (1974a) studied for 4 years the effect of clipping and grazing on swards of _Setaria sphacelata_ (Schum) Stapf cv. Nandi with and without nitrogen fertilization or in mixture with either _Desmodium intortum_ or _D. uncinatum_ where all treatments were cut at 8-week intervals. He found that, in the first year, cut and grazed swards gave about the same dry matter yield. However, in the subsequent years, the dry matter yields of the grazed plots were considerably higher than the cut plots.

It is apparent that different species, whether in pure stands or in mixtures, react differently to clipping or grazing treatments and that extrapolation of results from clipping experiments to grazing practice is often not advisable.

Response of Pasture Plants to Defoliation

In general, forage and pasture plants respond in one way or another to intensity and time of defoliation. The physiological explanation of this phenomenon was well consolidated in the 40's and the 50's (Weinmann, 1943; Williams, 1946; Watson, 1952; Brougham, 1956)

and has become a very important concept in the management of swards, whether they be mechanically harvested or grazed, or whether they be single-species or mixed swards.

The generally accepted concept is that, when all environmental factors are favorable, the speed of recovery of grazed or mechanically harvested forage plants is associated with two principles: (1) the leaf area index and (2) the organic food reserves present in the tissues of the plant after defoliation. Blaser et al. (1962) added to the above (3) the location of the meristematic tissue that forms new shoots and leaves and (4) the morphological characteristics of the species as important factors in the differential response to defoliation. They indicated that, because of those factors, species are affected differently by defoliation and methods of grazing utilization.

In his classical work, Brougham (1956) found that, when a ryegrass-white clover-red clover sward was cut at 2.5, 7.5, and 12.5 cm above ground, it took approximately 24 days after defoliation for the sward cut at 2.5 cm to have almost complete light interception (95% or over), whereas the swards cut at 7.5 and 12.5 cm intercepted almost all the incident light 16 and 4 days after cutting, respectively. The growth rate of the pasture increased until complete interception of incident light, after which an almost constant maximum rate was sustained. The rate of increment of forage dry matter per unit of leaf (leaf efficiency) was greatly affected by defoliation intensity. Leaf efficiency was initially lower after a severe defoliation than after lenient defoliation, but it increased rapidly to a maximum and then declined gradually. He found that maximum efficiency for swards cut to 7.5 and 12.5 cm above ground occurred when maximum growth rate

was first attained. The heavily defoliated sward reached a maximum level of efficiency during the phase of accelerating growth.

Forage legumes and grasses store energy as readily available carbohydrates in various plant parts (Smith, 1973). Since reserve carbohydrates are used to start growth in the spring and after defoliation, it is of interest for the pasture specialist to be faimilar with the organs in which reserves are stored in different forage and pasture plants in order to achieve proper management.

Forages, because they are grown to be constantly defoliated, either mechanically or by grazing animals, have their normal seasonal carbohydrate trends modified by these management practices. Thus, the effects of defoliation on accumulation and use of carbohydrate reserves are of major concern in regard to forage plants (May, 1960; Smith, 1973; Brougham, 1956; Humphreys, 1966). Generally, great damage occurs when cutting or grazing takes place during periods of minimum food reserves. Continued defoliation by cutting or grazing at immature stages of growth will eventually exhaust the plant and weaken it to the extent of death. Plants weakened by too early, too frequent, or too heavy cuttings or grazing usually are more susceptible to drought, heat, cold, and disease.

Some factors other than defoliation affect carbohydrate reserves in forage plants, namely, temperature (Baker and Jung, 1968; Wilson and Ford, 1971), light (Baker and Jung, 1968; Sprague, 1944; Auda et al., 1966), moisture (Brown and Blaser, 1970), and soil nutrients (Waite, 1958; McLeod, 1965).

Since dry matter accumulation is dependent on organic food reserves as well as on leaf area index, grazing and cutting management should be practiced in such a way as to achieve maximum conversion of

solar radiation to plant product by maintaining a leaf canopy to allow a minimum amount of light to reach the soil surface and possessing characteristics leading to maximum photosynthesis.

The Pasture-Animal System

Forages are grown for the animals. Because of their value, the animals must have priority over the plants. However, a conscientious rancher should aim at optimum relationships between the plant and animal factors if a sustained profitable cattle raising enterprise is to be achieved.

Pasture production should be viewed as an interrelationship of factors which involve two basic biological systems, namely, the "pasture sward" and the "grazing animal" (Matches, 1970); any factor which influences either of those systems will affect the output per animal and the pasture output per unit area of land.

Animal output is dependent upon the amount and quality of forage produced and its conversion when consumed by the animal. Mott (1973) considered the forage production per unit area of land in terms of a feed unit as the "quantity" aspect of animal production, and the response of the animal to the pasture as a measure of its "quality *in toto*" if the animal potential is constant and the pasture is the only source of feed to the animal and quantity is not limiting.

One of the primary objectives in pasture management should be to define the plant-animal relationships affecting pasture and animal outputs.

Animal and Pasture Potential

The concept of animal and grassland potentials (Ivins, 1958) was recently emphasized (Matches, 1970) as an aid for a better understanding of the pasture-animal system and, consequently, for interpretation of results of grazing experiments.

Animal production from pastures is determined either by the potential productivity of the grazing animals or the potential productivity of the pasture. The pasture potential may be viewed as the maximum amount of herbage available for the grazing animal and, if all the grazeable forage is consumed, the pasture potential is reached, whereas animal potential for production is accomplished only when all grazing animals on the pasture are performing at their maximum capabilities under the prevailing conditions of grazing management (Matches, 1970).

The animal potential is dependent upon the types and genetic characteristics of the livestock, health, previous treatment, age, sex, size, environmental effects and all other factors which influence animal production other than immediate nutrition. On the other hand, the sward potential, in terms of animal production, is dependent upon the amount of forage available and its quality and is determined by the pasture composition, stage of growth, fertilizer treatment, rainfall, management practices, and other factors influencing forage production (Ivins, 1958; Mott, 1966, 1973).

Ivins et al. (1958) stated that "at any one time, our techniques of grassland evaluation with livestock measure either the animal potential or the grass potential--whichever one is the limiting factor in the animal/pasture complex. The connecting links between the two potentials are primarily rate of stocking, appetite and also palata-

bility of the herbage which in itself, through restriction of intake under conditions of low palatability, may impose a restriction on animal production." The same author illustrated situations when pasture potential exceeds animal potential, when they are equal (a rare situation), and when animal potential exceeds pasture potential, to indicate their effects upon different responses which may be expected from the animal-pasture system, and their implications in conducting grazing experiments. From these illustrations, it is clear that animal potential must exceed grassland potential if one expects responses (in terms of animal production) from treatments (fertilizers, irrigation, etc.) if stocking rate is not increased. For example, pasture potential may exceed the animal potential when pastures are not sufficiently stocked to utilize the available forage. In this case, gain per animal may be a maximum so that animals rather than the pasture treatments set the maximum of production. Therefore, the effects of the treatments on the potential grassland productivity would not be measured.

Nutrient Recycling in the Soil-Plant-Animal System

In a soil-plant-animal system, the soil supports the plant and, in turn, the plant supports the animal. But the grazing animal is not just a "parasite" in the system.

It has long been recognized by Stapledon (1926, cited by Watkins, 1957) that the grazing animal, with its return of dung and urine, can make important contributions in maintaining high-yielding pastures.

Mott (1974) reviewed some of the current concepts of nutrient recycling mechanisms to assess their consequences upon agronomic practices and livestock management. He presented a simplified pathway of

the recycling mechanism in which the soil, the plant and the animal represent pools of nutrients identified in recycling. In his illustration, the pool of nutrients of the soil is in equilibrium with the residue (or litter) pool, the latter representing a transitory state, since the litter represents the primary pathway for the return of nutrients into the cycle. He added that "the nutrient uptake by pasture plants and their consumption by the grazing animals represent only temporary delays in the flow of nutrients. Under intensive grazing management, the quantity of plant residue is reduced to a minimum, and retention of nutrients by the grazing animal represents only a small fraction of that consumed. Most of the nutrients consumed pass through the animal and are returned to the pasture in the excreta." It is widely known that up to 90% of mineral nutrients and nitrogen are returned in excreta of grazing animals making them an effective vehicle for retention and frequent reutilization of nutrients in the system (Mott and Popenoe, 1975).

In general, the most frequent sources of nutrients to the soil-plant-animal system are (a) return of excreta by the grazing animal, (b) fertilizers, (c) supplemental feeds, (d) nutrients from atmosphere, either from atmosospheric precipitation or symbiotic and non-symbiotic nitrogen fixation (Mott, 1974).

The grazing animal undoubtedly plays a major role in the turnover and retention of nutrients in the plant-soil-animal system. For example, Watkins (1957) found that the response of a grass-clover sward to applied nitrogen was very dependent on the presence or absence of the animal excrements; the urine caused a marked increment in the nitrogen and potassium content and yield of the pasture, especially when returned in quantity to a high-producing grass-dominant sward.

In comparison with urine, dung had very little effect on the chemical composition of the sward. In conclusion, he indicated that, together, as in normal grazing, dung and urine tended to counteract or enhance their individual effects.

In another study, Till and May (1970) found that, after 3 years, the sulphur from an original gypsum application to the soil was still being turned over in the soil-plant-animal system and that there had been no change in total sulphur. Besides, a large portion of the soil sulphur did not enter the sulphur cycle. Herriott and Wells (1963) reported the results of trials to investigate the effects of sheep excreta on the growth and yield of swards of grass alone or grass plus clover. They found, for their conditions, that the return of excreta had little effect on the pasture output, the main effect being for the pasture to become progressively more grass dominant. They also found that the recovery of excreta nitrogen appeared to be influenced by rainfall and the age of the sward. Another conclusion was that, on a soil naturally low in potassium, this element and nitrogen both affected the pattern of the forage regrowth and composition when returned in the excreta.

There are many factors which affect the rate of transport of nutrients in a soil-plant-animal system. Mott (1974) indicated stocking rate and insect fauna as factors which may increase availability and accelerate the rate of transport of nutrients in grazed pastures.

It is evident that more attention should be given to the different soil-plant-animal ecosystems to assess not only the detrimental effects of the grazing animal on the system, but also its beneficial influences in order to determine optimum conditions for sustained productive soil-plant-animal environments.

Stocking Rate, Grazing Pressure, and Carrying Capacity

Stocking rate, carrying capacity, and grazing pressure are terms which have been used widely in pasture research, especially in grazing experiments. They have often been misinterpreted and misused by some pasture specialists and, principally, by the layman.

Stocking Rate

Mott (1960) defined stocking rate as the number of animals per unit area of land, the term bearing no relationship to the amount of forage.

A considerable number of grazing trials have been conducted in the past 4 decades in which stocking rates have been included as a variable, and sometimes as the only variable. A general rule is that increases in stocking rate result in decreased gain per animal, but gain per unit land area is increased.

McMeekan (1956) emphasized the importance of stocking rate compared to kind of grazing management systems and kind of stock in the conversion of pastures to animal products. He considered stocking rate to be the most powerful weapon influencing the efficiency of pasture conversion to animal products on a per unit area basis.

Riewe (1961) reviewed a number of stocking rate studies and found that, in most cases, a significant negative correlation existed between stocking rate and gain per animal. However, he found exceptions, and the two most notable ones were that (1) the lightest stocking rate did not always produce the highest gain per animal and (2) the heaviest stocking rate did not always produce the greatest gain per unit area.

McMeekan and Walshe (1963), in a large-scale grazing experiment

conducted with dairy cows over a 4-year period, compared rotational with continuous grazing, each system at light and heavy stocking rates. They concluded that stocking rate was the most important factor affecting the efficiency of pasture utilization as measured by output of milk and butterfat per unit area. In general, the high stocking rate resulted in higher outputs per unit area of land despite lower performance per animal. They also found significant interactions between grazing method and stocking rate. Under continuous grazing, a point was reached at which output per unit area decreased to the vanishing point with increased stocking rate as a result of an excessive depression of performance per cow; this point was not reached under rotational grazing at the same high stocking rates.

In a similar study, but with beef cattle, Conway (1965) compared continuous and controlled grazing, each at three stocking rates, namely, 1.0, 1.75, and 2.5 animals per acre. He found that by increasing the stocking rate from 1.0 to 1.75 animals per acre, liveweight gain per animal declined but liveweight gain per acre increased. With a stocking rate of 2.5 animals per acre, liveweight gain was further reduced as was liveweight gain per acre. Here, again, the stocking rate was of greater significance than the grazing system. At the high stocking rate, cattle had sufficient dry matter only in the first part of the grazing season, whereas, at low stocking rates, dry matter production was sufficient to meet the animal's requirements.

For 3 years, Hancock (1958) studied the effect of level of nutrition as determined by stocking rate and the use of supplementary concentrates on milk yield and efficiency of production. He found that cows which received concentrate at the low stocking rate produced 45%

more milk than those which received no concentrate at the high stocking rate. Cows which received no concentrate at the low stocking rate produced 16% more milk than those at the high stocking rate with no concentrate. However, milk production per acre was 30% higher for the treatment at high stocking rate without concentrate than for treatment with low stocking rate without concentrate. He concluded that the greater milk production per cow at the low stocking rate was due to their capacity to maintain a similar forage intake level whether or not they were fed concentrate.

In most of the literature, there is general agreement with the above findings. Among the few exceptions, Lucas and McMeekan (1959) found that rate of stocking did not affect milk or butterfat production per cow. But, again, stocking rate had a strong influence upon production per acre, and milk production per acre was highest with the higher rate of stocking due to more complete utilization of available forage.

Grazing Pressure

Grazing pressure was defined by Mott (1960) as the number of animals per unit of available forage. He also pointed out that the term "grazing intensity" is sometimes used as a synonym for grazing pressure. He called attention to the fact that "in comparisons between plant species, species mixtures, fertility treatments, grazing-management systems and trials of similar nature in which animals are being used to measure the pasture output, it is imperative that the grazing pressure imposed on each of the treatments should be equal."

Of course, through sward-animal manipulation, grazing pressure can be varied or kept nearly constant. It can be varied, for example,

in trials where the direct effects of grazing pressure are to be tested.

Carrying Capacity

Carrying capacity is another term frequently used in pasture research and was defined by Mott (1960) as the stocking rate at the optimum grazing pressure.

The number of animal days per unit area of land, or the average number of animals for a given period of time, are measures which should express the yield of the pasture. The carrying capacity, if the stocking can be assumed at near optimum, should be the investigator's best estimate of the production of the pasture in terms of animal numbers (Mott, 1960).

Generalized Relationships Between Stocking Rate or Grazing Pressure and Animal Production

Generalized relationships between stocking rate or grazing pressure and animal performance and animal products per unit area have been presented by Harlan (1958), Mott (1960, 1973), Riewe (1961), Petersen et al. (1965), and Jones and Sandland (1974).

Harlan (1958) made the first attempt to express the generalized relationship between stocking rate and liveweight gain per animal and liveweight gain per unit area. He divided the range of stocking rate into light, moderate, heavy, and very heavy. From his proposed curve (a double exponential equation) for gain per animal (1) one full degree of grazing increment beyond the heavy stocking rate will invariably result in loss of weight, (2) livestock must either gain or lose weight, i.e., an equilibrium could not be established by manipulating the stocking rate, (3) the heavy stocking rate will yield a higher

gain per unit area of land than moderate or light, since higher gain per head at moderate and light stocking rates is not sufficient to offset the smaller area per head at the heavy stocking rate (grazing rates must be very close to the peril point before gain per unit area decreases materially), and (4) gain per head on heavily grazed pastures should, in general, be more variable than on moderate or light stocking rates. Harlan also indicated the general form of the curve for gain per unit area which increases with increases in stocking rate up to a point after which further increases in stocking rate will considerably reduce gain per acre to a minimum or to a vanishing point. He also discussed the practicality of those theoretical relationships. Harlan used stocking rate in terms of acres per animal. Using the reciprocal of this term (animals per acre), a straight line is obtained for the relationship between stocking rate and gain per animal (Riewe, 1966).

Theoretical provisional curves to describe the relationship between gain per animal and produce per unit area were discussed but no equation was presented.[1]

Riewe (1961) reviewed a number of grazing studies from every section of the United States to determine the relationship between stocking rate and animal gain. His relationship indicates that animal gain is increased as stocking rate is decreased. However, a point may be reached where a further reduction in stocking cannot result in an increment of gain per animal. He stated that, "if a further reduction

[1]G. O. Mott. 1956. Theoretical relationship between grazing pressure and the various units of measure determined in the grazing trial. Agron. Abstr. p. 84.

in stocking rate results in the forage becoming rank and advanced in maturity, it may well be that animal gain would be decreased. If only three stocking rates are used and the highest stocking rate is lighter than that required for maximum gain per animal, then a high correlation would not be expected." In general, his relationships indicate that increasing the stocking rate decreases animal performance, but gain per unit area is increased up to a point of maximum gain per area, after which animal performance continues to decline, but the gain per area also declines. His work also indicates that the stocking rate at the point of no gain is approximately twice the stocking to produce the maximum gain per unit area of land.

Mott (1960) indicated that it does not seem appropriate to suggest actual values for the constant in the equation presented by Harlan (1958) for the stocking rate-gain/animal relationship, except for specific sets of data, because the shape of the product-per-animal curve will certainly differ for different ratios of feed requirements for maintenance to feed requirements for performance.

The optimum grazing pressure concept was then proposed (Mott, 1960). He suggested a generalized curve of the relationship between stocking rate and gain per animal of the form

$$y' = k = ab^{x'}$$

where

y' = the ratio of product per animal to the product per animal at the optimum grazing pressure

x' = the ratio of stocking rate to the stocking rate at the optimum grazing pressure

and k, a, and b are constants.

As a consequence, a generalized curve was presented for gain per unit land area of the form

$$z' = x' y'$$

where z' is the ratio of gain per unit land area to the gain per unit land area at the optimum grazing pressure. Those relationships indicate that, if a pasture is stocked below the optimum rate, higher gain per animal will result, and at light stocking rates, stocking rate has very little affect on gain per animal over a wide range. Stocking rates higher than the optimum will greatly affect performance per animal because feed supply is reduced and selectivity declines considerably to the point where all feed produced in the pasture is consumed for maintenance and gain per animal will be zero. The author suggests that "the optimum stocking rate can only be defined as an optimum range and that this stocking rate is somewhat below that which will give maximum product per acre."

Petersen et al. (1965) produced a number of equations based on a series of assumptions and quantitative theory which indicate that gain per animal is constant as stocking rate increases to a "critical" point, and beyond this point, gain per animal is inversely related to stocking rate; on the other hand, as stocking rate increases to the "critical" point, gain per acre increases linearly, then declines linearly with further increments in stocking rate. In discussing the paper of Petersen et al. (1965), Cowlishaw (1969) indicated that, in relation to gain per animal, their conclusions related only to an instantaneous context and that, in practice, the available forage is not of uniform composition, selection takes place and, therefore, the digestibility of the forage consumed declines with increases in stocking rate. Furthermore, the requirements for maintenance of the graz-

ing animals also change as they grow and fatten. As suggested by Matches (1970), it is interesting to note that the quantitative theory of Petersen et al. (1965) is the animal and pasture potential suggested by Ivins (1958). For instance, until stocking rate is increased to the critical point, grassland potential exceeds animal potential.

Mott (1973) presented a more elaborated version of the concept of optimum grazing pressure where the generalized curve to represent the relationship between grazing pressure and gain per unit area seems to more adequately represent a reality. The relationships indicate that the optimum grazing pressure must be considered as an optimum range which is a compromise between output per animal and output per unit area. The author emphasized that the discussion of grazing pressure relates only to animal output and does not take into account the optima for plant species in the pasture.

From results of a number of grazing trials in temperate and tropical areas, Jones and Sandland (1974) derived relationships between stocking rate and gain per animal. As in Mott (1960, 1973), their results were expressed on a common basis by calculating the optimum stocking rate and relating ratios of gain to ratios of stocking rate relative to that at the optimum. They proposed a linear relationship between stocking rate and gain per animal in accordance with those found by Harlan (1958), Riewe (1961) and Cowlishaw (1969). The proposed relation was of the form

$$Y_a = a - bx$$

where Y_a is the gain per animal, x is the stocking rate, and a and b are constants. As a consequence, the relation between gain per unit

area (Y_h) and stocking rate (x) will be

$$Y_h = ax - bx^2$$

They also indicated that the maximum gain per unit area occurs when $x = a/2b$. The authors stated that "it now seems clear that the data from long-term grazing trials where several stocking rates have been used is consistent in support of the linear relation between gain per animal and stocking rate, even to the point where animals are gaining very little weight."

From all the above evidence, it seems apparent that maximum sustained yields of animal products per land area from pasture takes place with good forage utilization where there is some sacrifice in product per animal and, because animal outputs are strongly allied with grazing pressures, it is feasible to establish production goals per animal within narrow limits. By "controlling and varying grazing pressures, the production per head and unit of land can be wisely compromised for various phases of animal production" (Blaser et al., 1974).

Fixed Versus Variable Stocking Rate

In grazing experiments, the number of animals per unit area is either fixed for a period of at least some months or the number of animals is varied by the experimenter as frequently as the availability of forage requires (Wheeler et al., 1973).

Fixed versus variable stocking rate has been a very controversial issue in pasture research, and there are pros and cons for both systems.

To determine yield per animal and per unit area in grazing experiments, Mott and Lucas (1952) proposed the use of (a) variable

number of animals during the grazing season, (b) constant number of animals, adjusting the size of the experimental pasture, and (c) a constant number of animals, the unconsumed or accumulated forage being utilized by lengthening the grazing season or harvested for hay. In the first case, the number of animals per pasture or treatment could be adjusted to the desired stocking rate with what they called "grazer" or put-and-take animals. Consequently, the put-and-take method involves grazing experiments where the stocking rate is variable.

Because in most grazing experiments it is obviously necessary to measure the effect of treatments on animal performance, Blaser (1956) suggested the term "testers" for animals which should remain on the pasture treatment throughout the grazing period or, if possible, throughout the whole experiment.

Mott (1960) indicated that a fixed stocking rate across all treatments in a grazing trial can hardly be expected to measure differences in carrying capacity if such differences result from the treatments. He added that, "if the number of animals per unit area is to give an accurate appraisal of carrying capacity, then this unit of measure must not be fixed but be subjected to adjustment, so that the number of animals per unit of forage is maintained at an equivalent level for all treatments."

Another reason for the use of variable stocking rate is that, when comparing grazing systems, the output per animal or the output of herbage per unit area of land may be affected and, in such circumstances, fixed stocking rate will allow for the measurement of gain per animal only, but not of the carrying capacity of the pasture (Mott, 1960).

In some grazing experiments, the effect of selective grazing can be adjusted in order to obtain reliable treatment data by putting in or taking out animals from the pasture to make forage availability similar for different treatments. Also, in grazing experiments where the effect of different designated defoliation pressures are to be measured, variable stocking would be necessary.

Ivins (1958) suggested that when two pastures have the same stocking rate, a real difference in animal product may not be detected because the maximum intake requirements of the two groups of animals may be satisfied, or more than satisfied, by the forage production of both the inferior and superior swards.

Many investigators have questioned the use of variable stocking rate. For example, Morley and Spedding (1968) indicated that farmers cannot alter the number of cattle frequently and, thus, the results of grazing experiments where variable stocking rate is used do not apply to practical farm grazing conditions. They also included economic considerations. Wheeler (1962) and Wheeler _et al_. (1973) also questioned the practicality of the put-and-take technique as far as the application of results to farm conditions. Others like Kennedy _et al_. (1959) indicated that results may be unreliable due to the subjectiveness involved in adjusting the stocking rate of the different pastures according to the amount of herbage which seems to be available. This view is also shared by Wheeler (1962).

Even though the subject is controversial, Wheeler _et al_. (1973), after reviewing the literature and evaluating the consequences of the use of either the fixed or the variable stocking rate, indicated that both stocking methods have a place in conducting grazing experiments. He suggested that variable stocking rate tends to be appropriate for

the study of components of farm systems and that fixed stocking will serve in the study of the system "per se." He also discussed the use of the two methods along with the forage evaluation scheme proposed by Mott and Moore (1970).

Matches (1970) contended that most arguments against the use of the put-and-take method seem questionable and presents literature evidence for his contention. He stated that "one of the most powerful aspects of the put-and-take method is that, when grazing pressure is maintained at definable levels throughout the season, the quality and quantity time trends of the sward can be identified. Average stocking rate can still be computed at various intervals of the grazing season to show the expected carrying capacity of different treatments throughout the grazing season." This information can be used in practice. He added that fixed stocking rate trials do not adequately take into account the animal and plant time trends which are fundamental to understanding the plant-animal system.

Blaser et al. (1974) proposed using fixed stocking rates for a forage-animal system but variable stocking within the same system to supply the nutritional needs of the animal and to improve the utilization of the pasture which fluctuates in availability during the year because of differences in growth rate; by adjusting the grazing pressures, it is possible to approximate the nutritional needs of the animals, which, in turn, can augment production efficiency.

Kennedy et al. (1959) stated that valid comparisons of animal production per unit area should be made only when the treatments are stocked at their maximum carrying capacity for which a satisfactory level of animal performance is maintained. Since such carrying capacity cannot be objectively determined, he proposed that all treatments

should be stocked initially at the same rate and then gradually increased until daily animal performance on one or more treatments starts to decline below the desired level of animal performance. Stocking rate of those treatments should then be adjusted to maintain animal production slightly below the desired level.

Variable or fixed stocking can be used, of course, with controlled, continuous or any other grazing plan or system. It seems apparent that the put-and-take system is more appropriate when the plant-animal relationships are to be defined, a major goal in pasture research.

Grazing Management Systems

In pasture-animal systems, the herbage has to be consumed and converted to animal products to be of value. It is clear from this review up to this point that light grazing pressure results in high animal performance but depresses animal product per unit area because much forage is left under-grazed and wasted. So, maximum production per animal and per unit of land area cannot be achieved at the same time.

Sound grazing management should be based on sound principles like those listed by Blaser _et al_. (1973): (1) Maintain the species or mixed association and botanical balance, (2) encourage rapid regrowth during and/or after grazing, (3) make wise compromises between yield and quality, and (4) minimize costly operations.

Forage utilization by grazing animals generally encompasses different grazing systems, namely, (a) continuous and (b) rotational. Rotational subsystems include (1) ordinary--one group of animals, (2) two groups--first and last grazers, (3) forward creep grazing,

(4) strip or ration grazing, and (5) stockpiling--canopies accumulated for periods of sparse growth or none (Blaser et al., 1973).

Shiftlet and Heady (1971) make a distinction between deferred rotation and rest rotation grazing in range management. They considered deferred rotation grazing as a grazing system implying no grazing until seed is mature on one unit during the first growing season, on another unit in the second year, and so on for each unit. On the other hand, in rest rotation grazing, one part of the range is ungrazed for an entire year or longer, while other pastures are ungrazed for a part of or perhaps all of a growing season.

McMeekan (1956) emphasized with authority that "in the conversion of pasture to animal products on high-producing grassland, three major factors can be used to affect efficiency: grazing method, kind of stock, and stocking rate." From his studies, he concluded that (a) in terms of animal product per unit land area, even extreme differences in grazing methods are associated with relatively small effects upon efficiency and (b) stocking rate is by far the most powerful weapon of the three influencing efficiency on a per-unit-area basis.

The quality of pasture herbage, as shown by output per animal and animal product per unit land area, is interdependent on stocking rate (or grazing pressure) and selective grazing (McMeekan, 1956; Harlan, 1958; Willoughby, 1959; Mott, 1960, 1973).

Grazing Management Systems and Animal Production

Grazing methods and rate of stocking (or grazing pressure) should be inseparable in grazing experiments where the conversion of pasture to animal products is to be evaluated. Mott and Lucas (1952) suggested

that at least three stocking rate levels should be used in comparing management systems, with subsequent testing for the existence of system versus stocking rate interaction. When Mott (1960) proposed the optimum grazing pressure concept, he stated that the failure of some investigators to graze their pasture at an equivalent grazing pressure accounts, to a large extent, for the lack of more consistent results in studies of grazing management systems.

A review made by Wheeler (1962) of the past history of grazing experiments comparing continuous versus rotational grazing revealed that, in experiments where variables such as cutting of unequal areas for hay, feeding of unequal quantities of supplements, and non-uniform stocking rates were excluded from the comparison, neither strip nor rotational grazing has proved significantly superior in production per animal or per unit land area to continuous grazing over a whole grazing season or a full year. Under those conditions, strip grazing superiority over rotational grazing is only of the order of about 5%. Wheeler's review indicates that the rotational technique is useful for the preservation of good quality forage for feeding in physiologically critical periods, and the conservation of surplus material as hay or silage. The author emphasized the difficulty in evaluating the results reviewed because of faulty techniques employed in the experiments and suggested points of interest for future grazing experiments where animal records are involved.

Wheeler (1960) indicated it was possible that the performance of the rotational grazing system in several comparative trials was less than its potential because rotation with fixed rest periods was adopted. In an experiment conducted over several months, pasture growth will vary so that, if the rotation is fixed, a variable quan-

tity of herbage will confront the animals at various time of the year.

After Wheeler's review, a considerable number of studies have been reported in the literature, and some are more relevant. In 1963, McMeekan and Walshe, working with dairy cattle, compared continuous and rotational grazing, each system at a low and a high stocking rate. They found that grazing method was less important than stocking rate but that, in general, rotational grazing was superior to continuous grazing both per animal and per acre. However, the average influence, even of the extremes of management, was only half of the effect of stocking rate. They also found a significant interaction between grazing method and stocking rate. Their results suggest that, under rotational grazing, the optimum stocking rate occurs at a level 5 to 10% higher than under continuous grazing. A reduction of 10 to 12%. in per cow yield, compared with more lenient grazing, corresponds with optimum stocking rate irrespective of the grazing method.

Shiftlet and Heady (1971), discussing specialized systems such as deferred rotation and rest rotation in range management, stated that livestock response from those systems appears most favorable with the least possible movement of livestock from one grazing unit to another. Apparently, systems that disturb livestock the least combine the advantages to livestock of continuous grazing and the advantages to pastures of no grazing.

Conway (1965) studied the effects of grazing method, stocking rate, feed restriction during winter, and hormones on the performance of beef cattle. Controlled and uncontrolled grazing were compared at low, medium, and high rates of stocking. He found no difference in response to controlled grazing at the low and medium stocking rate,

whereas, at the high stocking rate, there was a highly significant response. He concluded that controlled grazing has no advantage in terms of animal performance until high levels of stocking are reached, and that stocking rate is of greater significance than methods of grazing. He also found no significant responses from feeding supplements to cattle on pasture at low stocking intensities.

McMeekan and Walshe (1963) compared rotational with continuous grazing with dairy cattle and found no advantage in rotational over continuous grazing at moderate stocking rates, but they found significant interactions between grazing methods and stocking rate.

Another instance in which grazing system did not affect performance was reported by Delgado and Alfonso (1974). They compared three grazing systems: (a) 4-paddock, (b) 10-paddock, and (c) electric fence, each stocked at 3.5 and 5.0 bulls/ha. They found that gain per animal and gain per acre were affected by stocking rate and indicated that a system using more than four paddocks was of little value in terms of performance. The use of low or high stocking rates would depend on whether maximum individual performance or maximum beef per unit area were to be achieved.

Edwards (1974) studied two systems of grazing at three different stocking rates and found that liveweight gain per hectare was positively correlated with herbage yield and the number of grazing days per hectare. He suggested that liveweight per hectare could be predicted from herbage yields and grazing days, even though methods of intensity of forage utilization markedly affected liveweight gains, and that herbage yield allowed a reasonable estimate to be made of the carrying capacity of the pasture, provided that stocking rates were at the optimum level.

McFeely and Browne (1974) reported the effect of grazing intervals on animal product per hectare with bullocks grazing on ryegrass pastures. They found no effect of rest period on animal product per hectare.

Smith and Williams (1974) made studies by computer simulation on deferred grazing and suggested that animal response in liveweight gain was sensitive to stocking rate, length of deferment and the initial density of plants. The response to stocking rate increased with the length of deferment and initial plant density. The combination of stocking rate and length of deferment maximizing the response was found to vary widely, depending on the initial plant density and economic weights given to values of liveweight produced and herbage remaining at the end of the season.

In New Zealand, Dawson (1975) fenced 6.5 ha of alluvial soil into six strips with single electric wires 40 m apart; the animals were moved daily to a new paddock, their rotation being determined largely by feed availability, but also by their increasing requirements as the season progressed. Results of 3 years indicated that the grazing system could be successfully used in high rainfall areas and was associated with better animal performance. Among other things, the quantity of forage available per unit area affects the efficiency with which grazing animals harvest the forage in a sward.

Van der Kley (1956) and Willoughby (1959) found critical values in grass-clover pastures between approximately 1,000 and 1,700 kg per ha of green forage expressed as dry matter; below this level, the animals have increasing difficulty in harvesting even enough feed for maintenance. Of course, these figures would vary with type and density of pasture, growth stage, and previous nutrition of the animals.

Wheeler (1962) indicated that, except at times when the growth rate is inadequate, continuous grazing appears to provide feed in excess of the critical level more consistently than rotational grazing. He suggested that continuous grazing ensures a more reasonably uniform daily intake of forage than rotational grazing. Even under lax rotational grazing, when animals are turned into a new paddock, they consume forage well in excess of their calculated requirement.

One important consideration in favor of rotational grazing relates to animal health and, consequently, to animal production. In most cases, due to their physiology, ecto- and endo-parasites can best be controlled under rotational than under set stocking (Spedding, 1954, and Wilkinson and Wilson, 1959).

In general, output per animal under continuous grazing is often higher than under rotational grazing because of lighter stocking and herbage selection, and the often high yields of animal products per unit area under rotational or strip grazing or zero pasture systems may be attributed to better plant yields under alternating rest and harvesting as well as less ungrazed residue.

Grazing Management Systems and Pasture Production

It is unfortunate that most of the literature on the effect of grazing management and stocking rate (or grazing pressure) have not given much consideration to what happens to the pasture sward in terms of its total yield, botanical composition, quality and longevity. Much of this kind of information has been extrapolated from clipping experiments dealing with intensity and height of defoliation of pure grass or mixed sward (Blaser, 1966; Chamblee, 1962; Humphreys, 1966; Wheeler, 1960, 1962). Wheeler (1962) states it is probable that the

extrapolation of results of clipping trials to what occurs under grazing, particularly continuous grazing, is unsound. He indicates that strip grazing approaches most closely the intensity of defoliation found in most cutting trials, but, even in this case, it is not possible to consistently force animals to defoliate as severely as a mower without adversely affecting individual yield.

Grazing management systems affect pasture plants in a number of ways such as total seasonal yield, longevity of species, botanical composition and physiological stage of growth; here, leaf area index, organic food reserves, location of meristematic tissues which form new shoots or leaves and morphological characteristics of species play very important roles as far as grazing management systems are concerned. Because of those factors, species respond differently to defoliation and to various methods of grazing utilization (Blaser et al., 1962). Again, stocking rate (or grazing pressure) is implicit because grazing animals affect pasture yield due to over or undergrazing which affects selectivity of grazing, soil compaction due to trampling, uneven distribution of excreta, etc.

McMeekan and Walshe (1963), Petersen et al. (1965), and other researchers agree that excess forage will be available for consumption and gain per animal will be approximately constant if stocking rate is below the critical point. However, if the rate of stocking increases beyond the optimum, gain per animal will be inversely related to stocking rate, grazing pressure will increase, gain per unit area will rapidly decline, and the pasture well-being will be in jeopardy unless an appropriate grazing management system is adopted to compensate for the effects of heavy grazing pressure.

Wheeler (1962), referring to theoretical considerations support-

ing rotational grazing, indicated that, as far as carbohydrate reserves and position of growing points are concerned, under conditions where the daily consumption by the animals is much less than the herbage production, it may be that species will persist, although exhibiting slow restoration of reserves, because any one plant is rarely defoliated completely. However, under heavier grazing pressure, rest periods are essential for the maintenance of yield and perhaps botanical composition.

Based on the concept of optimum leaf area index (Broughman, 1956), it has been suggested by Donald and Black and by Davidson and Philip (1958, both cited by Wheeler, 1960), that, once the optimum leaf area index has been attained, continuous grazing would be the most suitable system of management. However, Wheeler (1962) indicated that, even though the utilization of light energy and, consequently, growth rate can be higher under continuous than under rotational grazing, this particular concept has not much application in practical pasture management.

Blaser (1959) stated that dry matter production is invariably higher with rotational grazing than with continuous grazing and larger species give the best yield responses to rotational grazing. He also indicated that, based on growth physiology and morphology, forage production may be expected to increase from lower to higher values for utilization practices in the order: (a) continuous grazing with constant stocking, (b) continuous grazing with controlled stocking, (c) rotational grazing with a narrow ratio of rest to grazing, (d) rotational grazing with a wide ratio of rest to grazing, (e) strip grazing, and (f) green soiling; the amount of available forage consumed follows the same trend.

Shiftlet and Heady (1971), after reviewing the literature in specialized grazing management systems in range management, indicated that many of those systems improve range condition, plant vigor, and uniformity of forage use, and that they are probably most useful on deteriorated ranges. After the range has been improved to a desired condition, the system needs to be changed or adjusted. They also discussed economic implications which, unfortunately, have been overlooked in most of the literature reviewed.

Persistance of Tropical and Subtropical Legumes

The first requisite for successful use of high yielding legumes for animal production under grazing conditions is their successful adaptation to local climatic conditions. Secondly, their nutrient requirements must be met to ensure high yield and maintenance. Finally, and most importantly, they must persist under grazing to secure a long lasting beneficial contribution to the companion grass, to the soil, and to the grazing animal.

The lack of persistance of tropical and subtropical legumes under grazing conditions has been a major problem as compared to temperate legumes.

Due to the great importance that tropical and subtropical legumes may have in animal production, many investigators have conducted clipping and grazing experiments in an attempt to find management systems compatible with legume persistance under grazing.

Response to Defoliation Under Clipping and Grazing

Much of the research done with tropical and subtropical legumes has been done under clipping conditions either as preliminary tests for further investigations under grazing or, sometimes, for direct extrapolations to the grazing situation. But, in this review, even though a few papers were reviewed where legumes were evaluated under clipping conditions, emphasis will be given to responses of legumes under grazing.

The length of rest period and intensity of defoliation generally affect the regrowth of most tropical legumes and variation may be found even between ecotypes.[1]

Watkins and Lewy-van Severen (1951) studied several grasses and legumes under different heights and intensities of cutting in El Savaldor and found that tropical kudzu (Pueraria javanica) and lablab (Dolichos lablab) were rapidly killed off as soon as cutting treatment started, while pigeon pea (Cajanus cajan) stands were so reduced that harvests were discontinued after 6 months. They concluded that the legumes were unsuited for pastures.

In Hawaii Whitney (1970) compared mixtures of Desmodium intortum with pangolagrass (Digitaria decumbens) or with kikuyugrass (Pennisetum clandestinum) with the grasses alone under different cutting intensities, with and without nitrogen. He found that cutting at a height of 13 cm was consistently better than at 5 cm for the legume, but differences were non-significant. Under optimum management with-

---

[1]L. R. Humphreys. Tropical pastures and fodder crops. Unpublished manuscript. Department of Agriculture, University of Queensland, 1974.

out nitrogen, D. intortum fixed over 300 kg of nitrogen per hectare per year in kikuyugrass mixtures.

In Australia, Jones (1967) reported results from a clipping trial in which yields of Siratro (Phaseolus atropurpureus) increased linearly from approximately 1,400 to 6,500 kg of dry matter per hectare as cutting intervals increased from 4 to 16 weeks. With a 4-week cutting regime, the Siratro stand was considerably reduced after one season. He suggested that these results may be of fundamental importance in the management of sub-tropical grass-legume pastures.

In Nigeria, Moore (1965) reported increased yields of a Centrosema pubescens/Cynodon plectostachyum pasture mixture from an 8-week cutting interval compared with a 4- or 2-week cutting regime. Even though the effect on the legume was not studied during the trial, subsequent sampling indicated that there had been no marked changes in botanical composition due to cutting frequency. The author did not mention when the subsequent sampling was made.

Imrie (1971) studied the response of five introductions and one cultivar of Desmodium intortum to two defoliation intensities under stress and non-stress soil moisture and found that both heavy defoliation and moisture stress reduced yield. He suggested that a genetic shift occurred in D. intortum in the direction of the lower yielding components which were most adversely affected by severe defoliation.

Jones (1973), in Australia, studied the effect of different cutting intervals and height of cutting on a sward composed primarily of Desmodium intortum cv Greenleaf. He found that the mean annual yield and desmodium percentage increased with increasing intervals (from 4 to 12 weeks). He also found a significant interaction between effect

of cutting interval and height of cutting on the yield of the legume. The legume persistance was good for all treatments, but plant numbers increased linearly with increases in cutting height from 7.2 to 9.5 plants m^{-2}. Groff _et al._ (1970), in Australia, compared three ecotypes of _Stylosanthes guyanensis_, two erect types (Endeavour and Schofield) and one decumbent type (Q.8442). The decumbent type produced higher yields of dry matter under close defoliation than the erect types. Infrequent defoliation (18-week intervals) depressed growth, particularly that of the erect types. They attributed the variation in yield between types and cutting treatments to the presence of a greater number of residual leaves below cutting height in the basal region of the decumbent plants.

In a 2-year study, Vincent-Chandler _et al._ (1953) found that cutting a _Pueraria phaseoloides/Melinis minutiflora_ mixture at 4- and 10-in. heights affected markedly the proportion of each component in the mixture. Cutting at a height of 10 in. increased the yield of _P. phaseoloides_ but did not affect that of _M. minutiflora_.

In Uganda, Olsen (1973) studied a _Desmodium intortum/Setaria sphacelata_ mixture under different cutting heights (8 and 20 cm) and intervals (3, 6, and 9 weeks). When cut at a height of 8 cm, total dry matter per hectare increased almost linearly with increasing lengths of rest period, but when cut at a height of 20 cm, there was little effect on yield of the mixture; however, desmodium content was higher than when cut at 8 cm. Olsen also indicated that the desmodium content was markedly depressed by cutting at 8 cm at the 3-week interval and that crude protein content and _in vitro_ organic matter digestibility (IVOMD) of the legume was not affected by cutting frequency. It was concluded that cutting at a height of 20 cm at intervals of 6 to 9 weeks was necessary

for the maintenance of desmodium in the mixture and a mixture so balanced would meet nutritional requirements of grazing animals.

In Florida, Kretschmer et al. (1974), in plot trials during a 2-year period, compared six tropical legumes in mixture with three tropical grasses and found that Desmodium intortum was the best legume because of its consistent production and early spring growth, besides having the highest content and yield of crude protein.

In Texas, Siewerdt (1974) studied the growth behavior and nutritive value of eight tropical legumes and found that the highest dry matter yield was produced by Dolichus lablab cv. Rongai, Centrosema pubescens, and Siratro (Macroptilium atropurpureum) and that Desmodium intortum and D. uncinatum had the highest cold tolerance.

In a 3-year clipping trial in which Siratro (Macroptilium atropurpureum) was grown alone and in mixture with Setaria sphacelata cv. Nandi and subjected to different cutting heights and intervals, Jones (1974a), found that Siratro density was reduced in the grass-legume plots to 30% of that in the corresponding pure stands, but density increased linearly as cutting interval increased and was not affected by cutting height. Density of S. sphacelata increased linearly with increases in cutting interval up to 12 weeks but declined sharply when cut every 16 weeks.

Keya (1974b), in Kenya, found that Setaria sphacelata/Desmodium intortum (or D. uncinatum) mixtures yielded dry matter and had crude protein contents which were similar to those to pure grass stands given 100 to 200 kg and 200 to 400 kg nitrogen per hectare per year, respectively. He also found that clovers made smaller contributions to dry matter yield and crude protein content and fixed less nitrogen than did each of the two desmodium species.

Falvey (1975), in Australia, found that mowing Townswille stylo

(Stylosanthes humilis) to a height of about 10 cm during the early and mid-wet season was the best treatment for the legume content of the pasture both for the dry season following and the wet season of the next year. He indicated that the low growing habit of this legume allows for close clipping or grazing without much injury to the legume.

In spite of the fact that results from clipping trials such as those reported above can contribute important information, their direct extrapolation to the actual grazing situation may be dangerous since many factors which are involved in a grazed pasture are eliminated in clipping trials. Investigators of tropical pastures have lately realized the importance of grazing trials for evaluation of tropical and subtropical legumes to be used in mixture with tropical and subtropical grasses.

Animals grazing a mixed sward, often selectively, eat one species in preference to another and generalizations about why this occurs cannot be made.[1] Sometimes it is associated with a plant being less hairy than another, seasonal differences, differences in chemical composition, in height, in physiological stage, or in structure of the mixed sward.

Stobbs (1975), studying the effect of fertilization and plant structure on intake of tropical pastures, concluded that fertilizer nitrogen increases dry matter and leaf yields, particularly in the uppermost layers of the sward of Setaria anceps cv. Kazungula, allowing cows to harvest large bites of immature herbage. Higher contents of stem and inflorescence in heavily fertilized swards can result in inaccessibility of leaf when mature forage is grazed.

---

[1]L. R. Humphreys. Tropical pastures and fodder crops. Unpublished manuscript. Department of Agriculture, University of Queensland, 1974.

It has been noted that legumes like Macroptilium atropurpureum and Stylosanthes guyanensis have few basal branches and this character is accentuated by long intervals between defoliation. However, S. guyanensis under continuous grazing at a moderate stocking rate develops quite a good network of basal branching which provides a satisfactory structure for growth.[1]

Grazing modifies the opportunity that tall or climbing plants have for shading shorter plants. Stylosanthes humilis, Trifolium repens, and Lotononis bainesii (Bryan et al., 1971) are shaded by taller companion grasses if heavy grazing pressure does not remove the companion grass to allow light into their canopy. On the other hand, dominance of climbing or tall legumes is generally promoted by lenient grazing pressures. Many species--for example, Glycine wightii or Macroptilium atropurpureum--have few basal buds and escape shading by climbing on their companion grasses. Their dominance in these circumstances is promoted by long intervals between grazing or by light grazing pressure.[1]

It appears that most of these differences may be controlled by appropriate grazing management systems in conjunction with changes in stocking rate or grazing pressure.

Work done in Thailand has been cited where, during the wet season, Panicum maximum was preferred to Stylosanthes guyanensis, while in the dry season, the reverse was observed.[1] Similar observations were made in Guyana.[2] These are important observations for developing grazing systems to better utilize those species.

---

[1]L. R. Humphreys. Tropical pastures and fodder crops. Unpublished manuscript. Department of Agriculture, University of Queensland, 1974.

[2]G. O. Mott. 1976. Personal communication. Department of Agronomy, University of Florida.

Brenes et al. (1949), in Puerto Rico, studied several forage species under grazing and found that Brachiaria mutica/Pueraria thunbergiana mixtures were very valuable for local conditions. They noted, however, that P. thunbergiana grown alone produced very low forage yields.

Still in Puerto Rico, Warmke (1952) found that, among many species of forage legumes, Indigophera endicaphylla was outstandingly successful under grazing. It comprised only 10% of the total pasture area but provided 39% of the total number of grazing hours; it was not damaged by trampling and recovered rapidly under grazing.

Under two grazing regimes, Yates et al. (1971), in Queensland, compared Sorghum almum in mixture with (a) Glycine wightti and Phaseolus atropurpureus, (b) lucerne (Medicago sativa), and (c) all three legumes. They found that, in general, the subtropical legumes yielded more than lucerne and were also more effective in increasing the grass yields. Lucerne and the subtropical legumes were strongly competitive when sown together and the effect of lucerne was particularly marked. However, the competitive effect was less pronounced with less frequent grazing. They found slight improvement of soil nitrogen in pastures containing legumes.

In Uganda, Stobbs (1969a) studied the effect of continuous grazing at four fixed intensities of stocking and one variable upon composition of a tropical grass-legume mixture, and reported that continuous heavy grazing reduced the proportion of Hyparrhenia rufa and caused considerable weed invasion, whereas Stylosanthes gracilis maintained a good stand and was independent of stocking rate. He concluded that S. gracilis appeared to be less susceptible to mismanagement than H. rufa and Sporobolus pyramidalis. A rotational system might have improved the persistence of H. rufa at high stocking rates.

In Brazil, Buller _et al._ (1970) tested a great number of tropical legumes under clipping conditions. Among those legumes, _Stylosanthes gracilis_ and _Glycine javanica_ exhibited superior quality and were further tested in a grazing experiment in mixture with pangolagrass (_Digitaria decumbens_). Establishment of the legumes with the grass and acceptance by livestock were good, but _S. gracilis_ did not persist for more than 2 years under grazing which the authors attributed to weakening of the plants due to year-round grazing.

Jones (1975) reported the persistance of Siratro (_Macroptilium atropurpureum_) in mixture with _Setaria anceps_ cv. Nandi under continuous grazing and observed that, at a high stocking rate, there was a reduction in crown numbers and a faster turnover of individual plants of Siratro than at a lower stocking rate. Also, seedling survival in the first year was slightly better under the high stocking rate, but, in the subsequent years, the low stocking rate was more beneficial for seedling survival.

Bryan (1970), in Queensland, studied changes in botanical composition of some tropical sown pasture mixtures and found that high stocking rates favored _Paspalum dilatatum_ and _Lotononis bainesii_ to some extent and reduced _Chloris gayana_, whereas low stocking favored _Desmodium intortum_ and reduced _P. dilatatum_. He also found that, while _Trifolium repens_ preferred wet soils, _L. bainesii_ and _D. intortum_ showed preference for dry soils. In that same country, in areas where soils suffered periodical flooding following heavy rains, Young and Chippendale (1970) were not able to attain satisfactory establishment of _L. bainesii_ and _D. uncinatum_ and maintain the established plants under grazing in mixture with pangolagrass, especially under high stocking rate.

In a 6-year grazing trial, Bryan and Evans (1973) compared the effect

of high, medium, and low stocking rates on a complex grass-legume mixture. They found that light stocking favored Paspalum commersonii, Digitaria decumbens, Desmodium intortum and Desmodium uncinatum and high stocking favorably affected Paspalum dilatatum, Trifolium repens, Lotononis bainesii and weeds. They also noticed that the legume content in all pastures decreased over time and grass content remained about the same.

Walker and Potere (1974), in Australia, studied the effect of stocking rate on plant populations in tropical legume-grass pastures made up of Setaria sphacelata cv. Kazungula, Stylosanthes guyanensis cv. Schofield, and Macroptilium atropurpureum cv. Siratro with (a) high and (b) low proportion of legumes, under 1.2, 1.7, 2.0, 2.5, 3.3, or 5.0 steers per hectare. They found that, after one year, the grass proportions were different in (a) and (b), but the legume proportions were similar and highest with 1.2 and 1.7 steers per hectare. Except for S. sphacelata, at the highest stocking rate, there was a trend for seedling population to decline with reduction in grazing pressure and this decline was associated with an increase in the amount of dead herbage.

In north Queensland, when Desmodium intortum, Desmodium uncinatum, Stylosanthes guyanensis, Vigna luteola, and six Glycine wightii cultivars were sown in mixture with green panic grass (Panicum maximum var. trichoglume) and each mixture given 0 and 400 kg superphosphate per hectare annually and grazed for 3 years, Gartner et al. (1974) found that green panic was dominant in the first 2 years, but legume yields increased in the third year, particularly on plots with superphosphate. They noted that, although D. intortum and D. uncinatum were adapted to the area, their ability to respond to high-yielding edaphic environments was limited by insect attacks.

In some studies, investigators have also reported both the quantity

and quality aspects of the pastures besides the effect of the animals on the pasture.

In Queensland, Evans (1970) found that, when different subtropical grass-legume mixtures were grazed at high stocking rates, level of animal production was closely associated with the legume content of the pasture, but it was decreased over a 3-year period. With a low stocking rate, the legume content was maintained at a higher level, but gains per hectare were lower than at the high stocking rate. He also pointed out the beneficial effect of annual phosphate dressings on the increase of legume content and of liveweight gains at all stocking rates.

Norman and Phillips (1970) found that the mean dry matter yield of Townsville stylo (*Stylosanthes humilis*) was not significantly affected by stocking rate, neither did they find significant differences in mean liveweight gain per head; thus, liveweight per unit area at the heaviest stocking rate was approximately twice that at the lightest rate.

In Uganda, Stobbs (1969b) studied the effect of 17.5-day and 35-day grazing cycles upon liveweight of zebu heifers on (a) *Hyparrhenia rufa*/*Stylosanthes gracilis* and (b) *H. rufa*/*Centrosema pubescens* mixtures and found small overall differences in animal production between grazing management systems and pasture treatment. During the dry season, liveweight gains were significantly higher under rapid rotational systems, but the authors made no measurements on herbage production or sward composition.

Stobbs (1969c) tested 3- and 6-paddock and continuous grazing systems on a mixture of *Panicum maximum* and *Macroptilium atropurpureum* for 4 years and found the highest animal production from the 3-paddock rotationally and the continuously grazed pastures and substantially less from the 6-paddock system. Only when the quantity of available forage was low

did the rotational grazing treatments show any advantage over continuous grazing. Continuous grazing resulted in higher legume content, whereas rotational grazing resulted in higher grass and lower weed contents. It was also concluded that the inclusion of the nutritious, drought-resistant M. atropurpureum into the pasture mixture contributed considerably in extending the forage quality during the dry season.

Stobbs (1969d) studied the intake of a mixture of Stylosanthes gracilis and Hyparrhenia rufa under grazing and indoors. Esophageal-fistulated animals on the grazing trial ate 27.8% of S. gracilis in a sward containing about 21% of the legume. He concluded that the legume was very palatable and emphasized its value in the dry season to offset the protein shortage of grass pastures.

Again, Stobbs (1971) found that milk production of cows grazing unsupplemented pure-stand pastures of Phaseolus atropurpureus cv. Siratro and of Greenleaf desmodium (Desmodium intortum) was low and did not differ between the two legumes. Intake of digestible energy was considered the major factor limiting milk yield. He concluded that it is unlikely that these legumes will be grazed in pure stands and that the proportion of Siratro and desmodium in a mixed sward has a pronounced effect upon milk production due to the relative acceptability and ease of harvesting them.

Bryan (1968) studied four different tropical grasses under grazing for 7 years. Even though the legume content of the pastures was low--only 13%--this had a major influence on animal production results. The legumes were Desmodium uncinatum, Lotononis bainesii, and Trifolium repens.

Tothill (1974), in Australia, studied for 3 years the effect of sod-seeding of Siratro (Macroptilium atropurpureum) into native speargrass on

animal production. He compared (a) unimproved woodland, (b) natural speargrass (Heteropogon contortus), (c) natural speargrass plus Siratro oversown with phosphorus and molybdenum and (d) buffelgrass (Cenchrus ciliaris) plus Siratro plus phosphorus and molybdenum sown on completely cleared land. In the first year, liveweight gains were greatest in (d). Overall, oversowing with Siratro gave 4- to 10-fold increases in liveweight gains per unit area and 1.4- to 2-fold increases in gain per head.

In Australia, Bisset and Marlowe (1974) studied the effect of three different stocking rates under continuous grazing on a mixture of Macroptilium atropurpureum cv. Siratro and Paspalum commersonii cv. Paltridge for 5 years at two different sites. The grass failed to persist on both sites. On one site, conditions were more favorable for Siratro for, even at the high stocking rate, it proliferated much more vigorously than at the low stocking rate at the other site. At this latter site, the highest stocking rate gave negligible Siratro yield and poor animal performance, while the lowest stocking rate gave co-dominance of Siratro and native grass and a similar liveweight gain per head to that of the pasture at the other site.

Mellor et al. (1973), in a 4-year grazing trial in Australia, studied four cultivars of Panicum maximum, each in mixture with Centrosema pubescens or with C. pubescens and Glycine wightii cv. Tinaroo at approximately the same grazing pressure. Common and Hamil guineagrasses were found to be the best cultivars of P. maximum and there were no overall advantages from growing a mixture of legumes with the grasses as compared with C. pubescens alone, though the inclusion of Tinaroo glycine with C. pubescens resulted in increased liveweight gains in autumn and winter.

Winks et al. (1974) conducted a grazing trial for 4 years where they

compared two stocking rates on a Stylosanthes humilis/natural grass pasture with and without superphosphate. They found that phosphate increased yield and quality of herbage and liveweight gains. Liveweight gains per animal were greater at the lower than at the higher stocking rate.

Cohen and O'Brian (1974), in Australia, in a 4-year grazing trial, studied a natural pasture dominated by Axonopus affinis and Bothriochloa decipiens with (a) no fertilizer, (b) superphosphate plus Trifolium repens, and (c) superphosphate plus Lotononis bainesii, Macroptilium atropurpureum, Lespedeza striata, and T. repens, all under three different stocking rates. They found that cows grazing (b) and (c) maintained higher liveweights and produced more and heavier calves. They concluded that phosphorus application and oversowing could increase stocking rates, liveweight gains, and fertility of beef cattle grazing natural pastures of the area. Similar results were also obtained by Lowe (1974) who found that liveweight gains of cattle grazing natural pastures oversown with Macroptilium atropurpureum were greater than of those grazing unimproved pastures. Oversowing also allowed the stocking rate to be increased.

Mannetje (1974) studied the relations between pasture attributes and liveweight gains on a subtropical pasture of Cenchrus ciliaris (a) without nitrogen, (b) with nitrogen, and (c) with Macroptilium atropurpureum. Liveweight gains of steers were related to total green matter, green grass, or green legume, and no relation could be found between liveweight gains and total dry matter, digestible dry matter, total nitrogen or digestibility or percent nitrogen of green material. It was suggested that the feeding value of the grass-legume mixture was sufficient to finish cattle for much of the year, and crude protein

levels of the green forage were always high enough not to restrict intake and to keep the animals in positive nitrogen balance.

In Fiji, Partridge and Ranacow (1974) studied animal performance of steers grazing Dichanthium caricosum in which 0, 10, and 20 percent of the area was sown with Leucaena leucocephala and fertilized with nitrogen, phosphorus and potassium. Steers grazing the paddocks made gains of 215, 300, and 500 g per head per day, respectively, and the annual liveweight gains were 110, 170, and 270 kg per hectare, respectively. They indicated that the legume was satisfactorily maintained in the pastures.

Jones (1974b), in a grazing trial in Australia, compared during 4 years Setaria anceps cv. Nandi with (a) nitrogen fertilizer, (b) Greenleaf desmodium (Desmodium intortum), and (c) Macroptilium atropurpureum cv. Siratro. Maximum annual liveweight gains per hectare for the pasture were desmodium (243 kg), Siratro (233 kg) and fertilized pastures (475 kg). At three steers per hectare, the legume pastures were severely over-grazed by the end of the fourth year, and legume production declined to virtually zero. He suggested that, for local conditions, for maximum gain per hectare, the stocking rate for the legume-based pastures was about two steers per hectare and, for nitrogen-fertilized pastures, five steers per hectare. He also indicated that the legumes can be recovered in the grass-legume pastures if grazing is excluded for some time.

Winter (1975) reported partial results of a grazing trial comparing (a) Hamil guineagrass (Panicum maximum) and (b) signalgrass (Brachiaria decumbens), both with a mixture of Siratro (Macroptilium atropurpureum) and Cook stylo (Stylosanthes guyanensis). Animal performance was better on Hamil-legume pasture in the wet season, but signalgrass-legume pastures have favored animal performance in the dry season.

In a grazing trial in Florida, Maraschin and Mott (1975), studied the response of Macroptilium atropurpureum, Desmodium intortum, and Lotononis bainesii growing in association with Coastcross-1 bermudagrass (Cynodon dactylon) and found that frequently grazed pastures tended to reduce legume persistence and to encourage grass mainly at high levels of grazing pressure while low levels of grazing pressure favored the maintenance of legumes.

With relation to tropical and subtropical grass-legume mixtures, Jones (1971, cited by Roberts,1974), stated that the variable cutting or grazing interval has had the most dominant influence on total legume and total pasture yield and that "it is reasonable to conclude that rapid rotational grazing would result in lower legume yields than in slow rotational systems in which the recovery time was 8 weeks or longer. Shorter rotations would result in higher stocking pressures, associated with yields and hence a further adverse influence on the tropical legume." Jones then suggested that the use of continous grazing, provided the stocking rate is not too high, would enable the legume to increase in summer when stocking pressure is lower and, under these conditions, the legume would not receive the sudden and drastic reduction in leaf area and in numbers of growing points experienced under clipping or close rotational grazing.

Roberts (1974) indicated that the factors which influence the stability of a grass-legume mixture are (a) relative growth rates of the grass and of the legume, (b) palatability of the grass and of the legume, (c) maximum height of the grass, (d) shade tolerance of the legume, (e) seedling regeneration, and (f) ability to withstand trampling. He suggested that continuous grazing helps the legume to compete better with the grass under all the above conditions than it could under a rotational grazing system.

As seen throughout this review, results varied for different species under different sets of environmental circumstances and, although some trends seem apparent to the management of tropical and sub-tropical grass-legume mixtures under grazing, no absolute generalizations can be made. It is clear, however, that, if legumes can be maintained in the pasture, there will be a beneficial effect in terms of gain per animal and probably animal product per unit area.

Forage Quality

Moore and Mott (1973) stated that "forage quality is best defined as output per animal and is a function of voluntary intake and digestibility of nutrients when forage is fed alone and *ad libitum* to a specified animal." Mott (1973) included the animal potential as a very important factor in the evaluation of forage quality. Environmental effects on the animals, previous treatments, age, size, sex, and genetic characteristics will certainly affect the evaluation of forage quality.

Sometimes, however, when grazing animals are used only as defoliators in a grazing trial, and it is not possible to use animal output as a measure of the quality of the pasture, the investigator has to rely on some other characteristics of the forage on offer which will hopefully predict its quality in the best way possible. In the last 15 years, *in vitro* organic matter digestion (IVOMD) or dry matter digestion (IVDMD) and the crude protein (CP) content of the forage of offer have been used as an attempt to predict forage quality either under barn or grazing conditions.

Digestibility

Digestibility has long been recognized as an important measure of the quality of feeds, including forages for ruminants as has been pointed out by Van Soest (1973). He also defined various measures of digestibility such as apparent and true digestibility as well as digestible energy and total digestible nutrients (TDN). *In vivo* digestion trials are the most reliable predictors of the digestibility of a forage. However, digestibility as determined by this procedure, besides being costly, can be influenced by ruminant species, frequency of feeding, adequacy of available water, ambient temperature and level of feeding (Riewe and Lippke, 1970). *In vitro* digestion techniques have been developed (Tilley and Terry, 1963; Van Soest, 1969; Moore *et al*., 1972) the results of which have been highly correlated with those of *in vivo* digestion trials. Johnson (1963) suggested that the *in vitro* digestion techniques are very useful in evaluating the quality of forages, and Mott (1973) indicated that the two-stage *in vitro* digestion technique proposed by Tilley and Terry (1963) or its modification such as that by Moore *et al*. (1972) are presently the most widely accepted procedures being used routinely. Of course, one of the most important advantages of the *in vitro* over the *in vivo* digestion technique is the fact that it is less time consuming, much less forage sample material is necessary, and a greater number of forages can be studied in a short time (Mott, 1973). However, forage sampling for predicting quality through *in vitro* procedures must be done in such a way as to approximate as best as possible the diet of the grazing animal. For example, Smith (1974) found that forage samples collected from esophageal-fistulated steers had higher *in vitro* digestibility and nitrogen content and lower cellulose content that those samples cut by hand. He

stated that voluntary intake and digestibility were the major factors influencing liveweight gains.

According to Riewe and Lippke (1970), the factors which affect digestibility of forages can be more easily understood if differences in their composition are kept in mind. They stated that the composition of forages may be affected by a number of factors including forages species, stage of maturity, and fertilization.

In general, there is agreement that stage of maturity is probably the most important factor affecting forage composition, and a forage becomes less digestible as it becomes more mature (Homb, 1953; Riewe and Lippke, 1970; Reid et al., 1959; Goonewardene and Appadurai, 1972; Coward-Lord et al., 1974; Minson, 1971; Moore and Mott, 1973; Van Soest, 1973). Van Soest (1973), however, pointed out that the effect is a complex response and is not guaranteed in all instances and that factors such as cool temperatures and light that retard maturity promote higher quality at a given age. He stated that in the fall, with decreasing temperatures, the nutritive value of a forage may actually increase with the age of the plant.

At the same stage of maturity, legumes have much less cell wall material than do grasses, and the cell walls of legumes contain considerably less hemicellulose and are more lignified (Riewe and Lippke, 1970). The same authors stated that, as grasses advance in maturity, the composition of the total cell wall material changes, but, in general, not drastically. However, lignification of the cell walls in legumes may increase sharply. On the other hand, Van Soest (1973) suggested that, at the same relative digestibility, grasses contain less lignin and much more hemicellulose than legumes, but the lower lignin content of the grass is offset by the greater hemicellulose and consequently

higher cell wall content; digestibility is about the same, but the intake and net energy values for grasses are lower than for a legume at the same TDN content.

Many authors (Van Soest, 1968; Sullivan, 1966; Minson and McLeod, 1970; Jeffery and Holder, 1971; Moore and Mott, 1973; Johnson and Pezo, 1975) have compared temperate with tropical and subtropical forage species in relation to their quality. Moore and Mott (1973) stated the low quality of tropical grasses is generally accepted as a fact in comparison with temperate grasses, but they warned that tropical grass quality is considerably variable and requires a complete evaluation before any conclusion can be made. Riewe and Lippke (1970) suggested that, in a similar stage of maturity, warm season annual grasses are lower in digestibility than cool season grasses. They added that the cell walls of the warm season annuals appear to have more lignin, but that both classes of grasses appear to have similar hemicellulose and cellulose content. As for the warm season perennial grasses, Riewe and Lippke (1970) pointed out that they are characterized by high cell wall contents and, while they may have a cell wall content lower than 50% when they are very young, they rapidly reach a cell wall content of 70% or higher. An outstanding feature of warm season perennial grasses seems to be the more rapid increase in cell wall material as compared to that of temperate grasses, either annual or perennial, apparently due to rapid growth or dry matter accumulation. Moore and Mott (1973) presented selected data where maximum DM or OM digestibility exceeded 65% in most cases and frequently was higher than 80% in temperate grasses while, in tropical grasses, those values were seldom higher than 65% and never greater than 80%. In this respect, Hamilton <u>et al</u>. (1970) suggested that, in terms of DM, OM, or energy, a

digestibility of 65% in a tropical grass should allow adequate intake of digestible energy for dairy cattle.

Even though, in general, digestibility declines with advanced maturity of all forage plants, the rate of decline is not the same for temperate and tropical forages. This aspect was reviewed by Moore and Mott (1973). Some figures indicate that DM digestibility of temperate grasses declines circa 0.5 percentage units per day (Reid et al., 1959), and the rate of decline in digestibility of temperate species is considerably less in regrowth than in the first growth in the spring (Minson et al., 1964). Minson (1971) found a range of 0.7 decrease to an increase of 1.3 percentage units per day for tropical grasses, but the most frequently observed change was 0.1 to 0.2 percentage unit decrease per day. The lower rate of decline for tropical grasses may be attributed to the fact that digestibility studies of tropical grasses have often involved long periods of regrowth. In studies with Cynodon dactylon, Adams et al. (1972, cited by Moore and Mott, 1973) found that the digestibility of the organic matter of the grass declined in a sigmoid rather than a linear fashion during the 2nd to the 12th week of regrowth. Similar results were obtained by Ventura et al. (1972, cited by Moore and Mott, 1973) working with Digitaria decumbens.

In fertility studies with Coastal bermudagrass (Wilkinson et al., 1970), it was observed that the bottom layers of the grass sward were significantly less digestible than the upper layers of the canopy. The lignin content was almost twice as much towards the bottom of the sward, and this was independent of fertility levels.

Crude Protein

The crude protein content of forage dry matter or organic matter is an important characteristic for determination of the nutritional status of the animal. Minson and Milford (1967), cited by Moore and Mott (1973), suggests that the level of crude protein below which nitrogen is the first limiting factor in a tropical grass is about 7% on dry matter basis and, according to Haggar and Ahmed (1970), protein may often be the first limiting factor in tropical grasses. Moore and Mott (1973) suggest that the crude protein percentage be examined first when an explanation of an unexpected low production is observed before looking for other limitations such as those related to structure, other nutrients, and toxic agents.

With relation to digestibility of organic or dry matter, many authors have found that, as crude protein content declines, IVOMD or IVDMD also declines and this decline is negatively correlated with increase in maturity or with going deeper into the canopy of the pasture (Minson et al., 1964; Cruz and Benachio, 1965; Wilkinson et al., 1970). Homb (1953) and Butterworth (1961) are also among those authors who have found that crude protein content of forages declines with maturity. Homb (1953), however, suggests that the decrease is faster early in the season.

Milford and Haydock (1965) found that the crude protein content of six tropical grasses declined rapidly until 40 to 60 days. From then on, the decline was slower, resulting in a non-linear relationship. Similar findings were reported by Bredon and Horrell (1961).

For Pangola digitgrass, Butterworth (1961) observed that the apparent digestibility of protein declined in a pattern similar to that of the percent of protein with increasing grass maturity. Milford and Haydock

(1965) reported zero apparent crude protein digestibility when the crude protein percent was 3.9.

Forage intake may be limited by the crude protein content of the forage. Dry matter intake was low when low-protein forage was fed to sheep (Milford, 1960). In another study (Milford and Minson, 1966), it was reported that intake declined rapidly when crude protein content of the forage fell below 7%.

Moore et al. (1969) found that forage with 8.6% crude protein or less furnished inadequate digestible protein for growing cattle, and similar observations were made by Milford and Haydock (1965).

Statistical Procedures

In all fields of experimentation, the experimenter tries to explore a system by studying the factors which are known to affect it, adding and removing their effects, and ascertaining how the system reacts. Unfortunately, systems are generally too complex to be studied thoroughly, and practical and economical considerations limit even further the region of experimental variables which can be used in experimentation. This is true in biological systems and particularly true in agricultural field research where very complex dynamic systems are common.

In agricultural experimentation, not only the factors and/or levels of the factors which affect the system need to be selected adequately and objectively, but appropriate statistical procedures also need to be employed so that as much inference as possible can be made from the experiment within acceptable confidence limits.

Most statistical procedures found in the textbooks (Cochran and Cox, 1957; Wishart and Sanders, 1958; Steel and Torrie, 1960; Snedecor and Cochran, 1973) are used in agricultural research, each being more suitable

to particular sets of experimental conditions and objectives. Matches (1970) reviewed the literature on experimental designs that have been used in grazing trials and discussed an experimental design proposed for grazing trials involving several rates of stocking but no replication. He warned, however, that "unless the investigator has a complete knowledge of the variability or uniformity within his experimental site, it would appear hazardous to substitute several rates of stocking in lieu of replications." Lucas (1974) discussed the analyses of statistical designs that are most appropriate for experiments with milking dairy cows and presented critical features of good dairy feeding experiments.

For exploratory agricultural experiments, where the experimenter wishes to study as many factors as possible, factorial experiments have been used widely. Mendenhall (1968) referred to the fact that this type of problem has been generally regarded as "factorial-type experiments" rather than factorial designs and called them volume-increasing designs. He stated, however, that, even though a factorial experiment is primarily a volume-increasing experiment constructed to focus information on factor interactions and main effects, it also reduces noise.

Factorial experiments can be considered advantageous in the sense that (a) they allow more efficient use of the experimental information when estimating the effects, (b) the interactions can be determined, (c) the effects are estimated with greater precision for a fixed amount of experimentation, (d) the effects are studied over a wide range of conditions. They have a great disadvantage, however, in that they become prohibitively large with a moderate number of factors at few levels.[1]

[1]F. G. Martin. 1974. Mimeographed notes for course No. STA-605. Department of Statistics, University of Florida.

This increase in size also becomes a problem for blocking, since it may not be easy to find homogeneous blocks to accommodate a large number of treatments. Cochran and Cox (1957) and other text book authors have presented alternatives for reducing the size of blocks, the size of the experiment or both at the same time by using incomplete blocks, confounding, or fractional replicate techniques.

Box and Wilson (1951) introduced the idea of attaining optimum experimental conditions through the exploration of response surfaces. Their work was developed in chemical investigations where experimentation can easily be made sequential and experimental errors are fairly small. They based their investigations on the problem of finding experimentally the levels of a number of quantitative variables at which some dependent response is at a maximum value. In their paper, they discussed the sequential steps to attain a maximum or near-maximum response. The process involves mathematical derivation of the model which approximates the response in the region of the independent variables. The authors stated that there are two possible sources of error, one due to errors of observation, and the other due to bias which can occur if the assumed model does not represent the response adequately. They discussed the stationary point concept and presented aspects of the canonical transformation of the fitted model for ease of interpretation of the response surface analysis. They also presented factorial and composite designs to estimate effects of first and second order surfaces. These concepts were later reinforced and consolidated by Box (1954).

In agricultural research, sequential experimentation is not, in general, practically and economically feasible because the results cannot be obtained quickly. This is particularly true for forage evaluation and pasture management. For these conditions, it would be preferable to use

designs which allow the use of models to approximate the response in the region of the optimum, of which the experimenter should already have some estimate (Rojas, 1971). Another problem relates to the generally high experimental errors involved in agricultural research which have made the agricultural scientist reluctant to use response surface designs. Among the designs developed by Box and Wilson (1951) are the composite designs which have been looked at with interest by some agricultural researchers. These designs are constructed by adding further treatment combinations to those obtained from a 2^k factorial where k is the number of factors. In particular, the central composite design has the 2^k factorial with $2k + 1$ additional treatment combinations (Box and Hunter, 1954).

Rotatable designs, which provide constant variance of predicted responses at points equidistant from the center of the design, have been developed (Box and Hunter, 1957). In their paper, Box and Hunter discussed the requirements a design must have in order to be rotatable and presented some rotatable designs of first and second order. Cochran and Cox (1957) listed a number of rotatable designs for different numbers of factors.

Since the cost of experimental work in agricultural research is closely related to the number of treatments, it is desirable to have a minimum number of treatments and yet be able to obtain a full and accurate picture of the responses of interest. Therefore, the use of the response surface design should have a place in agricultural research.

However, it is not always possible to use rotatable designs in agricultural experiments because rotatability may not be compatible with agronomic requisites. Rojas (1962, 1971) elaborated a modification of Box's rotatable design and developed the "San Cristobal" design which complies with agronomic requisites normally involved in fertilizer ex-

periments with sugarcane. This design gives $2^k + k + 1$ treatments as compared to $2^k + 2k + 1$ for a second-order central composite design.

More recently, Littell and Mott (1974) theoretically compared modified with standard rotatable central composite designs in an attempt to adapt those response surface designs to different experimental situations. They list the advantages of the central composite designs but also state an important disadvantage, namely, that the criterion required for rotatability may be difficult to employ in practice.

In field experiments, the experimenter most probably will have to modify the formal designs generally by adding design points outside the experimental region of the formal Central Composite Design or to shift points around within the region of the experimental variables to concentrate information in areas of interest. Presently, with available package regression programs, it is possible, before the experiment is laid out in the field, to obtain modified Central Composite Designs, without much effect on the properties of the formal design (Littel and Mott, 1974). This is done by computing the variance of the predicted response $[V(\hat{Y})]$ at selected points in the region of the experimental variables of interest. $V(\hat{Y})$ cannot be actually evaluated without the knowledge of the experimental error σ^2. However, the authors stated that "σ^2 is only a constant of proportionality in $V(\hat{Y})$ and, thus, we can evaluate a quantity which is proportional to $V(\hat{Y})$ by replacing σ^2 with a fixed number, say one." Once the expected variance of the response at different points is obtained, one may then decide on the appropriate number of replications to be used of different points in the experiment (Dillon, 1966).

Balaam (1975) cited a number of authors who compared nonfactorial response surface designs with factorial experiments in agricultural experiments. For example, Robinson (1960), after comparing a 3^3 factorial

with a composite design of 15 treatment combinations, stated that, in the factorial experiment, the estimates of the linear, quadratic, and interaction effects are orthogonal and, in the composite design, the curvature effects are correlated. He went on to emphasize that "the composite design was developed on the basis of a polynomial response surface, and the use of other mathematical models will generally lead to complex calculations and may give rise to difficulties in interpretation."

Dillon (1966), however, suggested that complete factorials can be very inefficient for response surface estimations, especially if it is necessary to replicate to attain an estimate of the experimental error. He added that, if there are more than three factors under study, "the scattering of points in factorial experiments is so complete that, compared to composite and rotatable designs, factorial experiments are wasteful of research resources." He indicated that, compared to factorials, the central composite design allows a larger number of levels per factor which is an advantage because the more levels of each factor, the better the regression analysis.

Balaam (1974), concerned with the estimate of the experimental error in response surface designs, indicated that, "in the exact sciences, replication at the center point may be used to provide an estimate of error for the complete experimental region and, because of the relatively low variability, estimates of responses at other points will have reasonable precision. However, in agricultural research, it is inadvisable to concentrate so much attention on one treatment combination. The possibility that the error variance is heterogeneous should not be overlooked. Hence, it is usually better to replicate uniformly all experimental points so that homogeneity of error variance may be tested more efficiently."

Only in very few instances have response surface designs been used in pasture research. In Venezuela, Villasmil et al. (1975) used a response surface design called "San Cristobal" design (Rojas, 1962, 1971) in randomized blocks with two replications to test the effect of nitrogen, phosphorus, and potassium on the yield of guineagrass (Panicum maximum, Jacq). The authors also used the same response surface design in a grazing trial to study the effect of nitrogen, phosphorus and length of rest period on the production per animal and the production per hectare of guineagrass. Again, the design was used in randomized blocks with two replications.

In Florida, Maraschin (1975) used a modified central composite design in an agronomic experiment to evaluate the response of a grass-legume mixture under grazing. Kien (1975) also used a modified central composite design to evaluate the response of a number of tropical grasses to different levels of fertilizers.

In the above-mentioned studies, the analysis of the response surface was restricted to the factorial analysis with little or no emphasis given to analysis of the fitted surface as described by Box (1954), Box and Hunter (1957), and Myers (1971). In the context of the analysis, Williams and Baker (1968) stated that "factorial designs have an advantage over response surface designs in that they allow a full response surface analysis in conjunction with the usual factorial analysis. Response surface designs are not flexible in this sense. . . ." These authors indicated that the effective use of response surface designs would be restricted to rather unusual experiments such as where a central composite design could be used or where the region of the independent variables has unusual shape. They added that, if such conditions do not exist, factorial designs should be used and the results

should be analyzed using both the factorial and the response surface analysis.

However, there seems to be a general agreement in that, for three (depending on the number of levels) or more factors, response surface designs, namely, the central composite designs, would generally appear feasible for use in determining best operating conditions (Dillon, 1966; Robinson, 1960; Balaam, 1974). More specifically, Dillon (1966) stated that, for crop and pasture management trials involving three or more input factors, "composite and rotatable designs are to be strongly recommended because -

(a) they are the most economic of available designs in terms of research resources; and

(b) they are specifically designed for response surface estimation."

MATERIALS AND METHODS

The contents of this dissertation are intended to cover the results of the second experimental period of a grazing experiment which was initiated in 1973 at the Beef Research Unit of the University of Florida in Gainesville, Florida.

Although most of the material and methods used in this experiment were described (Maraschin, 1975), they will be repeated herein with appropriate modifications where needed.

Experimental Site: General Description

The Beef Research Unit of the University of Florida is located approximately 13 miles northeast of Gainesville on flat pine land commonly called "flatwoods."

According to Henderson (1939, cited by Koger et al., 1961), the original native vegetation consisted primarily of longleaf pine (*Pinus australis* Michx. f.), wiregrass (*Aristida* spp. and *Sporobolus* spp.), saw palmetto (*Serenoa repens* Bartr. Small), gallberry (*Ilesx glabra* L.), runner oak (*Quercus minima* Sarg.), and cypress (*Taxodium asendens* Brongn.).

Most of the soils in the general area vary from moderately well drained to very poorly drained (Koger et al., 1961). The soil of the experimental area belongs to the Sparr series which is characterized by acid horizons developed in thick beds of sandy and loamy marine sediments. In association with the Sparr series is the Blanton series in the best drained areas of the experimental site. In the Blanton series,

the water table rises to about 50 cm of the soil surface during the wettest periods of the year. Koger _et al_. (1961) stated that the average organic matter content of the general area is around 2.25%, but there is a wide fluctuation resulting from small differences in elevation and drainage, the best drained areas having organic matter as low as 1%. The average pH of untreated areas varies from 4.5 to 5.2, being higher in sites with lower organic matter content. The fertility of the soil is generally low. Average values from surface samples (Koger _et al_., 1961) indicated contents of 200 kg/ha of CaO, 14 kg of P_2O_5, and 54 kg/ha of K_2O.

Fig. 1 presents the mean monthly temperature and rainfall for 1974 and 1975 corresponding, respectively, to the first and second experimental periods. It also presents the average rainfall for the Gainesville area covering the period from 1931 to 1960.

Approximately 5 ha of land were used for the experiment, to comprise the experimental as well as the reserve pastures.

The Grass-Legume Mixture

The grass-legume mixture selected for the experiment consisted of Coastcross-1 bermudagrass (_Cynodon dactylon_ (L.), Pers.), Greenleaf desmodium (_Desmodium intortum_ (Mill) Urb.), lotononis (_Lotononis bainesii_ Baker) and Siratro (_Macroptilium atropurpureum_ (Moc et Sessé) Urb.). Because white clover (_Trifolium repens_ L.) is an endemic legume in the area and was present in about 40% of the area where the experimental pastures were to be laid out, it was also included in the mixture.

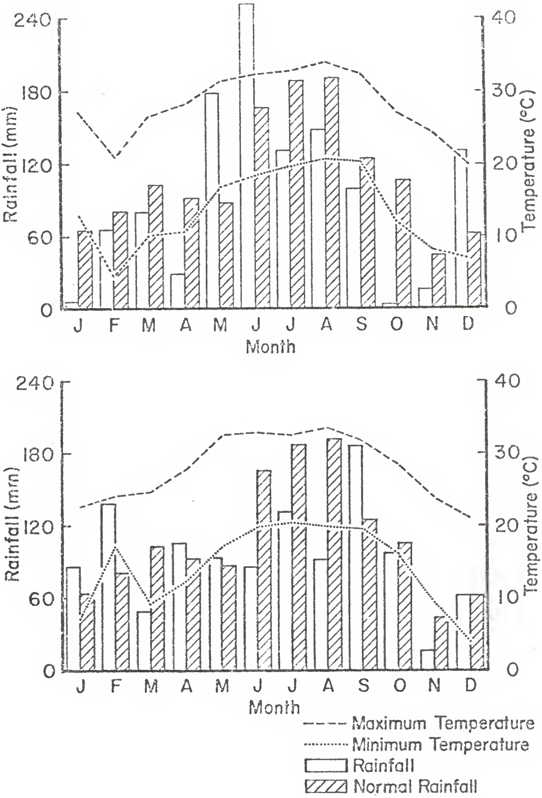


Fig. 1. Mean monthly temperature and rainfall for 1974 (upper graph) and 1975 (lower graph).

The Experimental Variables

The grazing management factors used as experimental variables were (a) length of grazing period, (b) length of rest period, and (c) grazing pressure.

In the first experimental year (Maraschin, 1975), grazing pressure was defined and expressed as kilograms of dry matter on offer per 100 kg of animal body weight. Due to heavy weed infestation, grazing pressure was also expressed in interpreting the results as kilograms of grazeable forage dry matter on offer per 100 kg of body weight per day. Still another expression of grazing pressure was the residual dry matter in metric tons per hectare left after grazing, which was a consequence of applying grazing pressure as the amount of dry matter on offer per 100 kg of body weight.

For the experimental period covered by this dissertation, grazing pressure was defined and expressed as residual dry matter in metric tons per hectare left after grazing.

Each experimental variable was studied in five levels. Therefore, the treatments comprised a factorial type of experiment of three factors, each at five levels (5^3 factorial).

For biological reasons and for ease of pasture measurements, the levels used for each factor were those presented in Table 1.

Because DM_R/ha is measured with error, ranges (Table 1) were established which were considered to be satisfactory. However, efforts were made to have DM_R/ha as close as possible to the projected DM_R/ha.

Table 1. The five levels of grazing period, rest period, and grazing pressure used in the experiment.

Grazing Period	Rest Period	Projected Grazing Pressure: DM_R/ha+ Projected	Range	DM_0/100 kg BW/day++
------days------		-----metric tons/ha----		---------kg----------
1.0	0	.500	.350 - .650	1.67
3.5	14	1.000	.850 - 1.150	3.33
7.0	28	1.500	1.350 - 1.650	5.00
10.5	42	2.000	1.850 - 2.150	6.67
14.0	56	2.500	2.350 - 2.650	8.33

+Residual dry matter per hectare left after grazing.

++Dry matter on offer per 100 kg of body weight per day. (Note: This column will be explained under heading Application of Grazing Pressure.)

Experimental Design

Because of practical implications of running $5^3 = 125$ treatments (without replication) in a grazing experiment, and considering its objectives, a response surface design, namely, a Central Composite Design was used. For ease of sampling and in order to accomodate the treatment combination of the factor levels, the design became a non-rotatable Central Composite Design. The Central Composite Designs consist of three sets of treatments, namely:

2^k factorial treatments (or factorial points)

2k axial treatments (or axial points)

1 (at least) central treatment (or central point).

The minimum number of treatments required is $2^k + 2k + 1$, which for this experiment was $2^3 + 2 \times 3 + 1 = 15$ treatments.

The central treatment, which would be expected to be close to the optimum combination of the experimental variables, was selected as:

7 days of grazing

28 days of rest

1.5 metric tons of residual dry matter left after grazing.

In order to have an estimate of experimental error, hence to be able to test the fit of the model used to approximate the response surface of the different response variables, the central point was replicated five times.

In addition to the factorial, axial, and central treatments, the Central Composite Design was modified by including six more treatments in the experiment. These extra treatments were added to the design in order to include intermediate levels of grazing days, days of rest, and grazing pressure between the central and axial points and to obtain a better test for lack-of-fit. However, due to insufficient space, one extra treatment (10.5 days grazing, 28 days rest, and 1.5 metric tons residual dry matter per hectare) later had to be omitted from the experiment. Table 2 presents the treatment combinations used in the experiment, and Fig. 2 shows the three-dimensional configuration of the design.

Lay-Out of the Experiment

Once the 20 treatments were obtained, the next step was to fit the 24 experimental pastures within the available land area. It was of interest to have pasture sizes as small as possible and yet each pasture should be able to supply forage for at least one animal during the most critical period of the experimental year. In order to attain the desirable pasture size for the different treatments, the equation

$$NdR = SDG \quad (1)$$

was used where :

N = amount of body weight (kg) per pasture

Table 2. The treatment combinations of length of grazing period, length of rest period, and grazing pressure of the Central Composite Design, plus the extra treatments.

	Treat. No.	Grazing Period (X_1)	Rest Period (X_2)	Grazing Pressure[+] (X_3)
		----days----		--metric tons/ha--
Factorial Treatments	1	3.5	14	1.0
	2	10.5	14	1.0
	3	3.5	42	1.0
	4	10.5	42	1.0
	5	3.5	14	2.0
	6	10.5	14	2.0
	7	3.5	42	2.0
	8	10.5	42	2.0
Axial Treatment	9	14.0	28	1.5
	10	1.0	28	1.5
	11	7.0	56	1.5
	12	7.0	0	1.5
	13	7.0	28	2.5
	14	7.0	28	.5
Central Treatments	15	7.0	28	1.5
	16	7.0	28	1.5
	17	7.0	28	1.5
	18	7.0	28	1.5
	19	7.0	28	1.5
Extra Treatments	20	7.0	42	1.5
	21	7.0	14	1.5
	22	7.0	28	1.0
	23	7.0	28	2.0
	24	3.5	28	1.5

[+]Grazing Pressure = metric tons/ha of residual DM left after grazing.

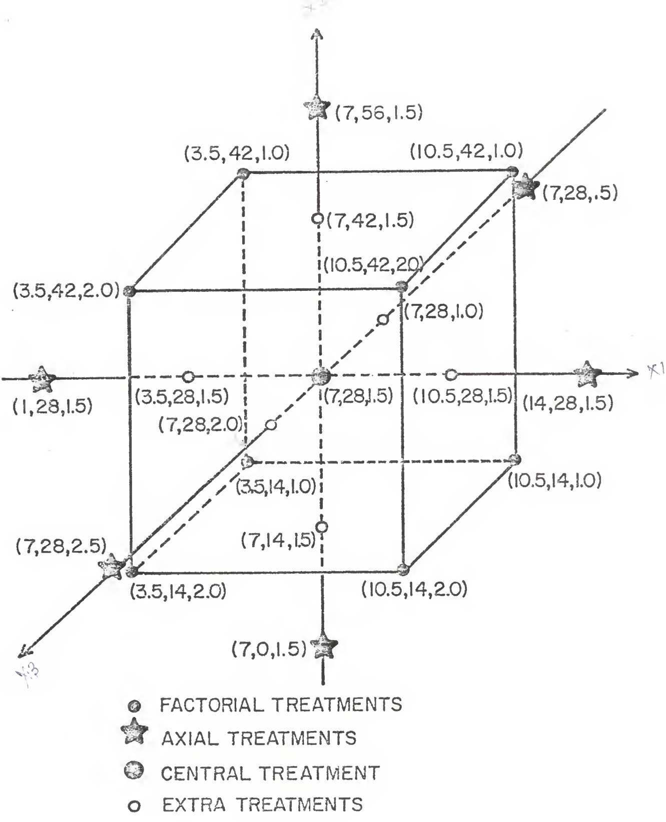


Fig. 2. Three-dimensional configuration of the modified Central Composite Design.

d = number of grazing days per pasture

R = amount (kg) of dry matter on offer per kg of body weight per day

S = size of the pasture in m^2

D = number of days in each complete cycle

G = growth rate of the pasture in kg per m^2 per day.

A simple transformation of equation (1) gave

$$S = \frac{NdR}{DG}$$

which was then used to calculate the pasture sizes for the different treatments. The following forage growth rates were assumed:

2 g per m^2 per day for 14 days of rest

4 g per m^2 per day for 28 days of rest

5 g per m^2 per day for 42 days of rest

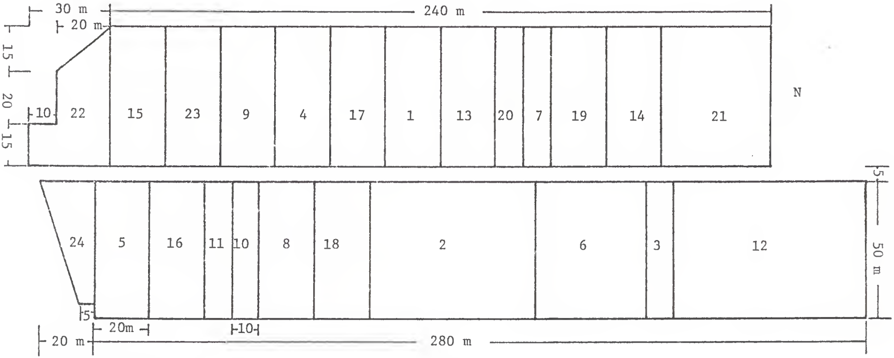
5 g per m^2 per day for 56 days of rest

As an example, for the treatment 7 days of grazing, 56 days of rest, and 5 kg DM_0/100 kg BW/day, the size of the pasture--assuming that the average weight of the animals to be used in the experiment was 300 kg--was calculated as follows:

$$S = \frac{300 \times 7 \times .05}{63 \times .005} = 333\ m^2$$

This figure was rounded off to 500 m^2 to avoid the inconvenience of many different pasture sizes. After the pasture sizes were found for the different treatments, these pastures were randomly distributed as shown in Fig. 3. The sizes of the experimental pastures varied from 500 m^2 to 3,500 m^2, the latter being for the continuously grazed treatment.

After the experiment was started, it was found that some of the pastures turned out to be unnecessarily large. The reasons for this were that (a) the forage growth rate--especially for short lenghts of rest period--was underestimated, and (b) the assumed forage consumption by



1:	3.5-14-1.0	5:	3.5-14-2.0	9:	14-28-1.5	13:	7-28-2.5	17:	7-28-2.5	21:	7-14-1.5
2:	10.5-14-1.0	6:	10.5-14-2.0	10:	1-28-1.5	14:	7-28- .5	18:	7-28-1.5	22:	7-28-1.0
3:	3.5-42-1.0	7:	3.5-42-2.0	11:	7-56-1.5	15:	7-28-1.5	19:	7-28-1.5	23:	7-28-2.0
4:	10.5-42-1.0	8:	10.5-42-2.0	12:	7- 0-1.5	16:	7-28-1.5	20:	7-42-1.5	24:	3.5-28-1.5

Fig. 3. Field layout of the experimental pastures with treatments as used in the second experimental year.

the experimental animals of 3% of their body weight was overestimated (Maraschin, 1975). The 24 experimental pastures comprised an area of 2.75 ha.

Land Preparation and Pasture Establishment

The development of the experimental area began in the fall of 1972 when the dominant grass, Pensacola bahiagrass (Paspalum notatum Fluegge.), was partially eliminated by an application of a grass killer herbicide. In the winter of that same year, the sod was plowed under. A repeat application of herbicide was made in the early spring of 1973 to eliminate some patches of common bermudagrass (Cynodon dactylon (L.) Pers.) which remained in the area. By this time, soil samples were taken to determine fertilizer needs. Table 3 presents the results of the analyses of eight composite soil samples from the experimental area. At about the same time, a few existing trees were pulled out from the experi-

Table 3. Soil analyses of eight composite samples (0-20 cm) of the experimental area, taken in the spring of 1973.

Sample No.	pH	CaO	MgO	P_2O_5	K_2O
		----------kg/ha----------			
1	5.9	2456	70	25	77
2	6.0	2457	126	31	109
3	6.0	1602	76	13	70
4	6.0	1449	76	11	77
5	6.0	981	76	20	85
6	6.1	880	76	9	55
7	6.1	981	52	7	39
8	6.1	1551	52	13	31
Mean	6.0	1545	76	16	68

mental area with a blade-mounted tractor and the debris removed by hand. Following this procedure, the area was cross-disced in order to eliminate annual weeds. In late June, the area was disced again to eliminate remaining weeds and was then leveled with a four-section harrow.

The next preparatory step was to disc in 750 kg/ha of finely ground dolomitic limestone, followed by a fertilizer application of 500 kg/ha of 0-14-14 fertilizer containing 39 kg of FTE 503/ton. The composition of the FTE 503 was: 3.0 B, 3.0 Cu, 18.0 Fe, 7.5 Mn, 0.2 Mo, and 7.0 Zn.

The first attempt at planting Coastcross-1 bermudagrass was made in July of 1973 in furrows approximately 10 cm deep and 90 cm apart. This first planting was almost a complete failure because of high temperature of the soil surface and lack of irrigation facilities. Another planting was initiated in the fall but was suspended because of lack of soil moisture.

In early August 1973, a mixture of Greenleaf desmodium, Siratro, and lotononis was sown at the rates of 1.6, 2.4, and 0.8 kg/ha, respectively, after each legume was inoculated with the appropriate strain of Rhizobium. The pelleted seeds were mixed with 400 kg of ground limestone and oversown on the recently cultipacked soil surface, using a Gandy fertilizer spreader. White clover was then broadcasted at the rate of 1 kg/ha with the use of a cyclone type seeder. Like the grass planting, the legume seeding was not completely satisfactory in 1973.

In November of 1973, a maintainance application of 200 kg/ha of a 0-20-20 was made using a Gandy fertilizer spreader.

In January 1974, eight more random soil samples were taken for a final assessment of the fertility status of the experimental area before

initiation of the grazing trial. Results of the analyses are presented in Table 4.

Table 4. Fertility status of the soil in January 1974.

Sample No.	pH	CaO	MgO	P_2O_5	K_2O
		------------kg------------			
1	6.2	1661	126	16	92
2	6.4	2323	76	7	112
3	6.2	981	70	11	87
4	6.4	1081	70	6	81
5	6.4	1295	70	11	81
6	6.3	981	76	11	92
7	6.4	1703	37	6	87
8	6.3	1935	52	18	98
Mean	6.3	1495	72	11	91

At the end of March 1974, about 60% of the area was replanted with Coastcross-1 bermudagrass. At the same time, a new seeding of Greenleaf desmodium, Siratro and lotononis was made at the rates of 1.0, 1.5, and 0.4 kg/ha, respectively. In April, an additional 200 kg/ha of 10-5-10 fertilizer was applied to secure a satisfactory establishment of the grass-legume mixture.

Construction of Physical Facilities

In the early spring of 1974, the area was surveyed for the location of the fence lines, and a four-strand wire fence was built. In May, a water supply system was installed using 2-inch PVC pipes with risers set every 10 m along the lane for livestock water and irrigation. Wooden mineral boxes were built, and water containers were provided, the water being controlled by a float valve. In the fall of the first ex-

perimental year (1974), the experimental pastures were irrigated once in order to bring soil moisture up to satisfactory levels for plant growth.

An area of approximately 5 ha adjacent to the experiment was available as reserve pasture, Pensacola bahiagrass being the predominant grass. Fig. 4 is a general view of the experimental area in the second experimental year.

Early Management and Collection of Data in the First Experimental Year

In the early spring of 1974, winter growth was grazed by cows and calves from the Beef Research Unit, and the remaining vegetation was mowed to a common stubble height. A severe infestation of late spring weeds had to be pulled out by hand. Notwithstanding, weeds were a major component during most of the first experimental year.

Twenty-four Braford yearlings were used to graze the experimental pastures. This reduced number of animals and the unnecessarily large size of some experimental pastures resulted in a shortage of animals during most of the season. This setback did not allow the attainment of the grazing pressure established in the original design, causing the analyses to be computed on the basis of grazing pressures actually attained rather than those to be imposed by the design.

The methods of measurement of the pasture and animal responses used in the second experimental year were similar to those used in the first year. A major difference occurred with relation to the application of grazing pressure. Somewhat different approaches were also employed with relation to botanical composition components and statistical analysis. From this point on, the material and methods will be described as they were used in the second experimental year.

Fig. 4. General view of the experiment as seen from the north.

Early Spring Management

In the early spring of 1975, visual evaluations indicated the need of replanting Coastcross-1 bermudagrass in some small bare spots which were not considered to be a result of treatment effects.

In spite of some definite trends in the Greenleaf desmodium percentage as a result of treatment effects, excessive weed infestation, and the somewhat irregular establishment of that legume in the previous year, its presence in the spring of 1975 was also somewhat erratic. However, Greenleaf desmodium was still the main legume component of the mixture, especially in treatments with long rest periods combined with lenient grazing pressure. Independently of treatment effects, there was a good deal less Greenleaf desmodium in 1975 than in the previous year. Some winter killing may have been the cause.

The presence of the legume lotononis was sporadic and in small patches early in the season, primarily in pastures located in well drained areas. This was also true for Siratro, but this legume started appearing later in the spring.

The weed percentage in the early spring growth was considerable. However, weed growth was markedly reduced as the season progressed, and it was possible to detect trends resulting from treatment effects.

In mid-April, over a period of about 10 days, all 24 pastures were lightly mob grazed by 26 heifers which were to be used as experimental animals. Immediately afterward, all pastures were mowed in order to leave a standing residue of approximately 1.5 metric tons DM/ha. This was followed by a fertilizer broadcast application of 300 kg/ha of the formulation 3-9-9, using a Gandy fertilizer spreader. This formulation contains small amounts of micronutrients needed by the legumes.

On May 10, 1975, the experimental period was initiated.

Management of the Experimental Animals

Thirty-seven Brown Swiss-Angus heifers were used to graze the experimental pastures. At the beginning of the experimental period, the average weight of the animals was 330 kg. Five approximately uniform heifers were selected to be testers, three of which were used to graze the five applications of the central treatment and two for the continuously grazed treatment. Due to the nature of the experiment, those were the treatments for which the effect of the pasture on animal performance could be evaluated. It was possible to maintain all three testers in the central treatment for most of the season. In the last cycle, only two testers could be carried by the treatment. However, in the continuously grazed treatment, only one tester remained in the pasture during the entire season.

The remaining heifers comprised a pool of put-and-take animals used at random to defoliate the experimental pastures whenever they were needed. In order to allow the testers to graze each replication of the central treatment in each cycle the five pastures were grazed in rotation with 7 days of grazing and 28 days of rest. All animals were weighed every 35 days.

Pasture Measurements

Dry Matter Determination Before and After Grazing

Dry matter/ha determinations before (on offer) and after (residue) each grazing period were made in order to apply the required grazing pressure, to determine forage consumption by the grazing animals in the period, the net dry matter production, and the stocking rate for the cycle.

A double sampling technique was employed. As soon as possible,

before and after each grazing, 20 areas measuring $0.5m^2$ were randomly selected, corresponding to the circular frame of a forage meter (Fig. 5), similar to the one described by Phillips and Clarke (1971), which was used in the double-sampling measurements. In each sampling unit, the percent dry matter yield of each component of the mixture was visually estimated, followed by an estimate of the total fresh forage yield. Then, the weighted disc of the meter was lowered on the forage and, after a settling time of about 5 seconds, the shaft was arrested and the corresponding height (in centimeters) was read from a graduated scale mounted on the frame of the meter.

From the 20 sampling units, five were randomly selected and clipped at ground level for actual dry matter determinations. Five other plots were selected in the same way and harvested for determination of the actual percent of each component. These five samples were frozen and later hand separated into their components. The sum of the dry weights of the components yielded the total dry weight of the sample. Final estimates of total dry matter were based on the 20 meter readings and the 10 clipped plots. A portable scale was used for weighing fresh forage samples in the field. Cordless, rechargeable grass clippers (Fig. 6) were used for harvesting the forage samples.

On the rotationally grazed pastures with grazing periods of 14 days and on the continuously grazed pasture, dry matter production and consumption were determined with the use of "paired" caged and uncaged areas. For each pair, one area in the pasture was selected at random and the other chosen similar to the first. One area was randomly selected to be caged and the other was left unprotected. Five cages, each covering an area of $1m^2$, were used in each pasture (Fig. 7). The continuously grazed pasture was sampled every 28 days. New paired areas

Fig. 5. The forage meter used in the experiment, showing the weighted disc (lowered), the graduated scale, and the circular frame.

Fig. 6. A cordless, rechargeable grass clipper cutting forage samples at ground level within .5m^2 of the circular frame.

Fig. 7. General view of the cages used in the continuously grazed pasture and in the treatment with 14 days of grazing.

were then randomly selected to be sampled at the end of the next 28-day period. Sampling inside and outside the cages involved the same double-sampling procedure as used in treatments with less than 14 days of grazing.

The fresh and the corresponding dry matter yields of the 10 clipped samples were used for correcting--through regression technique--the 20 visual estimates of total fresh yield, as well as the 20 indirect measurements of dry matter yield by the forage meter. The forage meter readings and visual estimates of fresh weight were used as independent variables in regression equations forced through the origin to generate the coefficients needed for the calibration of the forage meter and for adjusting the visual sample estimates. The regression coefficient was obtained from the equation

$$\hat{Y} = bX$$

where:

$\hat{Y}$ = estimated DM, metric tons/ha;

b = regression coefficient of height as measured by the forage meter on dry matter yield of harvested samples;

X = height of the forage as measured by the forage meter (in cm).

For the purpose of this dissertation, the forage dry matter available before (or after) each grazing period (in metric tons/ha) was estimated by the formula

$$\text{Dry Matter Before (or After) Each Grazing} = \frac{\bar{Y} + b\bar{X}_{10}}{2}$$

where:

$\bar{Y}$ = mean dry matter of the 10 harvested samples (in metric tons/ha);

b = regression coefficient as defined above (in metric tons/ha/cm);

$\bar{X}_{10}$ = mean height, as measured by the forage meter, of the 10 unharvested plots (in cm).

The average growth rate of the pasture during the rest period was estimated by the formula

$$\text{Growth Rate} = \frac{B_i - A_{(i-1)}}{\text{R. P.}}$$

where:

B_i = dry matter per hectare before grazing period i;

$A_{(i-1)}$ = dry matter per hectare after grazing period i - 1;

R. P. = number of days of rest.

The total dry matter available for each grazing period was estimated by the equation

$$\text{Total Available Dry Matter} =$$

$$B_i + \left(\frac{B_i - A_{i-1}}{\text{R. P.}} \times \text{G.D.}\right)$$

where:

G. D. = grazing days.

The net dry matter production for a given cycle was calculated from

$$\text{Net Dry Matter Production} =$$

$$B_i - A_{i-1} + \left(\frac{B_i - A_{i-1}}{\text{R. P.}} \times \text{G. D.}\right).$$

From the two last equations, it can be seen that the growth rate was assumed to be linear during a given rest period, as well as during the following grazing period.

For the continuously grazed pasture, for any given 28-day grazing period, the growth rate was calculated by

$$\text{Growth Rate} = \frac{I_i - O_{i-1}}{28}$$

where:

I_i = dry matter per hectare <u>inside</u> cage at the end of the 28-day period i;

O_{i-1} = dry matter per hectare <u>outside</u> cage at the end of the 28-day period i-1.

For the rest period and grazing period of the treatment with 14 days of grazing, the growth rate was also assumed to be linear. During the grazing period, the growth rate was estimated as follows:

$$\text{Growth Rate} = \frac{I_i - B_i}{14}$$

where:

I_i = dry matter per hectare inside cage after a 14-day grazing period;

B_i = dry matter per hectate before a 14-day grazing period i.

For the continuously grazed treatment, the mean amount of forage dry matter under the cages was an estimate of the forage dry matter on offer during a given 28-day grazing period. It corresponded to what was available after the previous grazing period plus that which grew during the 28-day grazing period. The difference between the amount of dry matter under the cage at sampling time (i) and the amount of dry matter outside the cage at sampling time (i-1) was an estimate of the net dry matter production for that period. The total available dry matter for a given 28-day period was

$C - A_{i-1}$

$$\text{Total Available Dry Matter} = I_i$$

where:

I_i = dry matter per hectare inside cage at the end of a 28-day period i.

The net dry matter production for a given 28-day period was calculated by

$$\boxed{\text{Net Dry Matter Production} = I_i - O_{i-1}}$$

where:

I_i = dry matter per hectare inside cage at the end of a 28-day period i;

O_{i-1} = dry matter per hectare outside cage at the end of a 28-day period i-1.

Dry matter consumption per cycle for the rotationally grazed pas-

tures (except for the treatment with 14 days grazing) was calculated according to the formula

$$\text{Dry Matter Consumption/Cycle} =$$

$$[B_i + (\frac{B_i - A_{i-1}}{R.\ P.} \times G.\ D.)] - A_i$$

where:

A_i = dry matter per hectare left after grazing period i.

For the continuously grazed treatment, dry matter consumption for a given 28-day period was calculated from

$$\text{Dry Matter Consumption/Period} =$$

$$I_i - O_i$$

where:

I_i = dry matter per hectare <u>inside</u> cage at the end of the 28-day period i;

O_i = dry matter per hectare <u>outside</u> cage at the end of the 28-day period i.

For the treatment with 14 days of grazing, dry matter consumption for a given cycle was also calculated from

$$\text{Dry Matter Consumption/Cycle} =$$

$$[B_i + (I_i - B_i)] - O_i$$

where:

I_i = dry matter per hectare <u>inside</u> cage at the end of the 14-day grazing period i;

O_i = dry matter per hectare <u>outside</u> cage at the end of the 14-day grazing period i.

The treatment totals of dry matter on offer and net dry matter production for the season were obtained by adding the yields from all cycles.

Botanical Composition Determinations

For each treatment in each cycle, the percent dry matter contribution of each component was obtained from visual estimates of 20 selected plots before and after grazing. Five plots were randomly selected and clipped for determination of actual botanical composition on dry matter basis. These five harvested samples were later used to adjust the other 15 visual estimates of a particular component using the formula

$$P = \frac{\bar{Y} + b\bar{X}_{15}}{2}$$

where:

P = mean percentage of total dry matter of a particular component;

$\bar{Y}$ = mean percentage of a particular component in the five hand separated samples;

b = regression coefficient of the five hand separated samples on the respective five visual percentage estimates;

$\bar{X}_{15}$ = mean of the 15 visually estimated samples not hand separated.

The regression coefficient (b) was obtained from the linear regression equation

$$\hat{Y}_p = bX$$

where:

$\hat{Y}_p$ = estimated percentage of a particular component

X = percent visual estimate.

The visual estimate of percent yield was made for the components grasses, desmodium, Siratro, lotononis, white clover, and weeds. Although Coastcross-1 bermudagrass was the major component of the grass portion, other grasses such as smutgrass (Sporobolus poiretii (Roem and Schult) Hitchc.) and bahiagrass, which were present in scattered, small clumps in some pastures, were included in the grass component. The

litter component was not visually estimated but was hand separated. This fraction was defined as any dry, decayed or decaying biomass not attached to physiologically active plant material. Because the samples were harvested at ground level, small amounts of sand were sometimes collected along with plant material. This sand was also included in the litter component. The separation of the litter fraction allowed for the percent yield estimates of the physiologically active components of the pasture mixture, before and after grazing (Fig. 8).

In order to assess the effect of the treatments on the changes in botanical composition with time, five $1m^2$ permanent quadrats were located in each pasture. The area for each quadrat was selected so that the most important components of the mixture were included in the quadrats in the beginning of the experiment. Visual estimates of ground cover were made every 35 days in the first year and every 14 days in the second year. The components included: Coastcross-1 bermudagrass, other grasses, desmodium, lotononis, Siratro, white clover, and bare ground.

Forage Quality Determinations

In vitro organic matter digestion (IVOMD) and nitrogen determinations were made on the physiologically active grass and Greenleaf desmodium components of samples taken before and after grazing for each cycle. Quality determinations were also made on a few litter samples of most treatments. The relatively insignificant and erratic presence of the other physiologically active components in the harvested samples did not allow for their inclusion in quality determinations.

The IVOMD and nitrogen determinations were made at the Forage Laboratory of the University of Florida. The five samples for each component in each cycle were dried at 60C for 24 hours, then ground in a

Fig. 8. Hand-separated components of the pasture mixture. From left to right: physiologically active grasses; litter; physiologically active Greenleaf desmodium; and physiologically active weeds.

Wiley mill to pass through a 1 mm screen. These ground samples were composited to represent the cycle.

The IVOMD was determined by the Tilley and Terry method (Tilley and Terry, 1963) as modified by Moore et al. (1972).

Application of Grazing Pressure

In the context of the second experimental year, grazing pressure was defined and expressed as the amount of standing residual dry matter left after a given grazing period. Table 1 shows the projected amounts of residual dry matter and their respective ranges. The table also presents, for each level of residue, a corresponding amount (in kg) of DM_0/100 kg BW/day. This second expression of grazing pressure was used to estimate the number of animals initially required to graze each pasture to the desired residue. During the grazing period, animals were then added or removed from the pasture in order to attain the projected grazing pressure. This was based solely on visual observations of the residue during the grazing period.

The accuracy of the application of the grazing pressures could be checked whenever desired, using the mean residual dry matter of the harvested samples after grazing.

Throughout the experimental period, the number of experimental animals available was sufficient for adequate application of the required levels of grazing pressure.

Response Variables

The response of the pasture mixture to the different combinations of the experimental variables was in terms of the following parameters:

Pasture Production and Yield

Total Dry Matter Available per Cycle - the average total dry matter available before and during each grazing period per cycle.

Growth Rate - the average rate of growth of the pasture mixture for the season.

Net Dry Matter - the total net dry matter production of the mixture for the season.

DM_0/100 kg BW/day - the season average dry matter on offer per 100 kg of animal body weight per day.

Stocking Rate - expressed both as the amount of liveweight and the number of animals carried by the pasture per hectare per day during the season.

Dry Matter Consumption - the average amount of dry matter consumed per 100 kg of body weight per day for the season.

Botanical Composition

Percentage of the physiologically active grass component.

Percentage of the physiologically active Greenleaf desmodium component.

Percentage of the physiologically active weed component.

Percentage of the litter component.

Forage Quality

IVOMD of the physiologically active grass component.

Crude protein content of the physiologically active grass component.

Litter IVOMD.

Animal performance.

In view of the fact that the many harvested samples of physiologically active Greenleaf desmodium did not provide enough plant material for analysis, the data for IVOMD and nitrogen content could not be analyzed in the response surface.

Statistical Analysis

The analysis of the response surface for each dependent variable consisted of the following steps:

1. Approximation of the response surface of each response variable with the function of the type

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

where:

$\hat{Y}$ = estimated response

X_1 = length of the grazing period (days)

X_2 = length of the rest period (days)

X_3 = grazing pressure, expressed as the amount of residual dry matter left after grazing (metric tons/ha)

b_0 = intercept (constant)

b_i = linear regression coefficient

b_{ii} = quadratic regression coefficient

b_{ij} = regression coefficient of the interaction terms.

In order to test the fit of the approximating model, the following analysis of the variance was performed.

Sources of Variation	d.f.	M.S.	F
Total	23		
Regression	9		
Linear	3		
Quadratic	6		
Residual	14		
Lack-of-fit	10		
Error	4		

The experimental error was obtained from the sums of squares of the deviations of the five replications of the central treatment from their mean, with 5-1 = 4 degrees of freedom. When the lack-of-fit for the approximating functions for the response variables studied was non-significant, the linear and quadratic components of regression were tested against the residual with 14 degrees of freedom.

Due to the unusually low experimental errors associated with some response variables studied in the experiment the value of F for lack-of-fit was considered to be significant only at the 1% level of probability ($P < 0.01$) or lower. If the model was found to adequately represent the response variable, then an analysis of the fitted surface was made.

2. The second step was to determine the location of the stationary point (SP) which is the point for which the derivatives $\frac{d\hat{Y}}{dX_1}$, $\frac{d\hat{Y}}{dX_2}$, and $\frac{d\hat{Y}}{dX_3}$ are simultaneously equal to zero. If a maximum (or a minimum) response existed, it was located at the SP. The SP for each response variable was then used as a reference point to aid in describing the response surface system.

3. The third step was the description of the response surface at the SP. For this phase of the analysis, the estimated regression equation was transformed to the canonical form which contains only quadratric terms. This transformation was necessary to more clearly interpret the response. The transformation (Myers, 1971) is a "translation" of the response function from the origin ($X_1 = 0$, $X_2 = 0$, and $X_3 = 0$) to the SP. From then on, the response function was expressed in terms of new variables, the canonical variables, W_1, W_2 and W_3, the axes of which correspond to the principal axes of the contour system. Graphs indicating the response surfaces were obtained by plotting contours of equal responses within the general domain of the experimental variables. The canonical equation was of the form

$$\hat{Y} = \hat{Y}_S + \lambda_1 W_1^2 + \lambda_2 W_2^2 + \lambda_3 W_3^2$$

where:

$\hat{Y}$ = the predicted response;

$\hat{Y}_S$ = the predicted response at the SP;

λ_i = constants;

W_i = canonical variables.

The signs and magnitudes of the λ_i's were used in determining the nature of the SP and the response system as follows:

> All λ's have positive sign: the response at the SP is a ~~maximum.~~ minimum
>
> All λ's have negative sign: the response at the SP is a ~~minimum.~~ maximum
>
> The λ's have different signs: the response at the SP is a maximum for experimental variables with negative λ and a minimum for those with positive λ.

4. In most cases, the response surface was described within the domain of the experimental variables used in the experiment. The relationship between the canonical variables (W's) and the actual experimental variables (X's) was determined in order to better visualize the response in the general region of the experimental variables. This was obtained from a matrix called M-matrix (Myers, 1971), which gives the following relationship

$$X_1 = X_{1S} + aW_1 + bW_2 + cW_3$$

$$X_2 = X_{2S} + dW_1 + eW_2 + fW_3$$

$$X_3 = X_{3S} + gW_1 + hW_2 + iW_3$$

where:

X_{1S} = the value of X_1 at the SP

X_{2S} = the value of X_2 at the SP

X_{3S} = the value of X_3 at the SP

a,b,---,i = constants.

Because of the difficulties in graphically representing a 4-dimensional response surface, for each response variable, two 2-dimensional sets of contours of equal responses were used to describe the response effect of the experimental variables. In each set of contours, either X_1 or X_2 was fixed. The SP was located in the contour maps if it was found to be within the experimental region, or in its vicinity, to indicate directions of responses away from the SP. If the SP was remote from the experimental region of the control variables, its direction was indicated. Unless necessary for sake of explanation, extrapolation outside the domain of the independent variables was avoided.

5. Another extension of the response surface analysis consisted of interpolations (within the region of the experimental variables) through manipulations of the approximating model based on the nature of the canonical equation. For example, for a fixed value of a control variable, the corresponding values of the other two which are required to give a maximum response were obtained, along with the corresponding maximum response at that point.

The basis for the decision of which control variable (or variables) to fix was the format of the canonical form. Suppose that the canonical equation was of the form

$$\hat{Y} = \hat{Y}_S + \lambda_1 W_1^2 - \lambda_2 W_2^2 - \lambda_3 W_3^2$$

The response at the SP would be a maximum in W_2 and W_3 and a minimum in W_1. It might be desirable to obtain the values of X_2 and X_3 for a fixed value of X_1 which would give a maximum response for that particular set of conditions.

Manipulation of the approximating model would give

$$\hat{Y} = (b_0 + b_1X_1 + b_{11}X_1^2) + (b_2 + b_{12}X_1)\, X_2$$

$$+ (b_3 + b_{13}X_1)\, X_3 + b_{22}X_2^2 + b_{33}X_3^2 + b_{23}X_2X_3$$

Taking the first derivative of $\hat{Y}$ in relation to X_2 and then in relation to X_3, and making them equal to zero (the canonical equation indicates that the response is a maximum in them),

$$\frac{d\hat{Y}}{dX_2} = b_2 + b_{12}X_1 + 2b_{22}X_2 + b_{23}X_3 = 0$$

$$\frac{d\hat{Y}}{dX_3} = b_3 + b_{13}X_1 + b_{23}X_2 + 2b_{33}X_3 = 0$$

the following system of equations would be obtained:

$$2b_{22}X_2 + b_{23}X_3 = -b_2 - b_{12}X_1$$

$$b_{23}X_2 + 2b_{33}X_3 = -b_3 - b_{13}X_1$$

Solving the system of equations, values of X_2 and X_3, say X_{2S}^* and X_{3S}^* are then obtained which, for a fixed value of X_1, maximize the value of the response ($\hat{Y}_S^*$). The response would then be estimated from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}\,(X_{2S}^* b_2^* + X_{3S}^* b_3^*)$$

where:

$b_0^* = b_0 + b_1X_1 + b_{11}X_1^2$

$b_2^* = b_2 + b_{12}X_1$

$b_3^* = b_3 + b_{13}X_1$

Similar procedures were used for different formats of the canonical equation.

The statistical analysis was done using the programs of the Statistical Analysis System (Barr and Goodnight, 1971) and the APL function (Gilmore and Rose, 1970) using the facilities of the Northeast Regional Data Center, University of Florida.

RESULTS AND DISCUSSION

Application of Grazing Pressure

Tables 5 and 6 present the observed residues left after grazing by grazing pressure (Table 5) and by treatment (Table 6) with the appropriate univariate statistics. Also included in the tables are the respective heights of the residues and the regression coefficients, with the appropriate statistics, used for correction of the unharvested samples. $DM_{R(A)}$ was used in the response surface analysis of the response variables.

The application of grazing pressure in this experiment was considered to be very satisfactory. The observed residues based on harvested samples ($DM_{R(H)}$) were within or very close to the respective pre-established ranges (Tables 5 and 6). After the unharvested samples were corrected and included in the estimate of the residual dry matter, the residues became slightly lower but still within or very close to the ranges.

The use of visual estimates of grazing pressure resulted in the pastures being slightly overgrazed. For all levels of grazing pressure, the observed residues were closer to the lower side of the pre-established ranges (Tables 5 and 6). One exception occurred in treatment no. 11 (7 days grazing, 56 days rest, and 1.5 metric tons/ha of residual DM) which was undergrazed, apparently because of the excessive maturity of the forage on offer at the lower levels of the pasture canopy and because litter accumulation prevented the animals from grazing the pasture to the desired level. However, the visually estimated height

Table 5. Residual DM left after grazing and respective height above-ground as measured by the forage meter (by grazing pressure).

DM_R (Projected)	DM_R^+ (H)				Height				Regression of DM on Height				$DM_{R(A)}^{++}$			
	n	$\bar{x}$	SD	CV	n	$\bar{x}$	SD	CV	b	S_b	CV	r	n	$\bar{x}$	SD	CV
metric tons/ha		-metric tons/ha-				-cm-			-metric tons/ha/cm-					-metric tons/ha-		
.350-0.650	50	.447	.196	44	100	4.8	1.2	25	.085	.005	41	.40**	100	.413	.09	21
.850-1.150	290	.910	.242	27	580	7.0	2.0	28	.124	.002	24	.55**	580	.870	.12	14
1.350-1.650	538	1.456	.366	25	1080	9.2	2.2	24	.152	.002	25	.43**	1080	1.400	.20	14
1.850-2.150	270	1.836	.379	21	540	10.4	2.4	23	.166	.002	20	.52**	540	1.760	.13	8
2.350-2.650	40	2.482	.458	18	80	12.3	3.0	24	.187	.006	21	.48**	80	2.328	.23	10

** $P < 0.01$

+ Residual DM based on harvested samples only.

++ Residual DM based on the average of harvested and adjusted unharvested samples.

n= number of observations.

$\bar{x}$= mean.

SD=standard deviation of the sample.

CV=coefficient of variation.

b= regression coefficient of the sample.

S_b=standard deviation of the regression coefficient.

r= sample coefficient of linear correlation.

Table 6. Residual DM left after grazing and respective height above-ground as measured by the forage meter (by treatment).

No.	Treatment GP	Treatment RP	Treatment DM_R (Projected)	No. of Cycles	$DM_{R(H)}$+ n	$DM_{R(H)}$+ $\bar{x}$	$DM_{R(H)}$+ SD	$DM_{R(H)}$+ CV	Height n	Height $\bar{x}$	Height SD	Height CV	Regression of DM on Height b	Regression of DM on Height S_b	Regression of DM on Height CV	Regression of DM on Height r	$DM_{R(A)}$++ n	$DM_{R(A)}$++ $\bar{x}$	$DM_{R(A)}$++ SD	$DM_{R(A)}$++ CV
	---days---		metric tons/ha			metric tons/ha				---cm---			metric tons/ha/cm					metric tons/ha		
1	3.5	14	1.0	10	100	.844	.225	27	200	6.5	1.9	31	.120	.003	24.2	.59**	200	.788	.100	13
2	10.5	14	1.0	7	70	.941	.208	22	140	6.8	1.9	28	.130	.003	21.6	.51**	140	.892	.070	8
3	3.5	42	1.0	4	40	.884	.248	28	80	7.2	1.9	26	.125	.005	26.6	.48**	80	.897	.120	13
4	10.5	42	1.0	3	30	1.003	.276	27	60	7.1	1.5	21	.140	.006	24.2	.52**	60	1.006	.020	2
5	3.5	14	2.0	9	90	1.775	.376	21	180	10.5	2.4	23	.165	.003	19.8	.51**	180	1.719	.150	9
6	10.5	14	2.0	6	60	1.779	.320	18	120	9.5	2.4	25	.175	.005	18.0	.44**	120	1.714	.180	10
7	3.5	42	2.0	4	40	1.876	.433	24	80	10.4	2.1	20	.175	.005	18.0	.65**	80	1.815	.060	3
8	10.5	42	2.0	3	30	1.975	.481	24	60	11.0	2.8	25	.168	.007	23.0	.56**	60	1.875	.040	2
9	14.0	28	1.5	4	40	1.446	.350	24	80	10.2	1.9	19	.142	.004	17.4	.70**	80	1.448	.090	6
10	1.0	28	1.5	6	60	1.557	.424	27	120	8.3	2.2	26	.184	.006	23.9	.56**	120	1.543	.220	14
11	7.0	56	1.5	3	30	1.808	.353	19	60	8.8	2.5	28	.201	.008	23.2	.51**	60	1.800	.140	8
12	7.0	0	1.5	6	60	1.240	.380	31	120	7.6	2.2	28	.158	.004	22.9	.68**	120	1.213	.170	14
13	7.0	28	2.5	4	40	2.482	.458	18	80	12.3	3.0	25	.187	.006	20.5	.48**	80	2.328	.230	10
14	7.0	28	.5	5	50	.447	.196	43	100	4.8	1.2	25	.085	.005	40.6	.39**	100	.413	.090	21
15	7.0	28	1.5	5	50	1.340	.300	22	100	9.7	2.1	22	.130	.003	16.6	.68**	100	1.264	.110	8
16	7.0	28	1.5	5	50	1.438	.351	24	100	9.3	2.3	25	.150	.005	23.6	.51**	100	1.410	.110	7
17	7.0	28	1.5	5	50	1.286	.308	24	100	9.0	1.9	22	.136	.005	25.5	.33**	100	1.245	.070	6
18	7.0	28	1.5	4	39	1.391	.312	22	80	10.0	2.1	21	.132	.004	17.3	.66**	80	1.341	.220	16
19	7.0	28	1.5	4	40	1.558	.367	24	80	9.3	2.0	22	.164	.005	20.2	.55**	80	1.548	.230	15
20	7.0	42	1.5	4	40	1.457	.338	23	80	9.4	2.2	23	.149	.005	17.4	.67**	80	1.409	.110	8
21	7.0	14	1.5	8	80	1.420	.362	25	159	8.6	2.4	28	.154	.004	25.5	.40**	159	1.344	.120	9
22	7.0	28	1.0	5	50	.962	.268	28	100	7.8	2.0	25	.118	.004	21.5	.64**	100	.917	.170	18
23	7.0	28	2.0	5	50	1.877	.306	16	100	11.2	2.2	20	.156	.004	16.0	.51**	100	1.755	.070	4
24	3.5	28	1.5	6	60	1.456	.339	23	120	9.3	2.1	23	.154	.004	21.0	.53**	120	1.448	.190	13

** $P < 0.01$

+ Residual DM based on harvested samples only.

++ Residual DM based on the average of harvested and adjusted unharvested samples.

$\bar{x}$= mean.

SD=standard deviation of the sample.

CV=coefficient of variation.

b= regression coefficient of the sample.

S_b=standard deviation of the regression coefficient.

r= sample coefficient of linear correlation.

of the residue and the height as measured by the forage meter were within the range observed for other treatments with the same grazing pressure. Figures 9, 10, 11, 12, and 13 show representative residues left after grazing of the five levels of grazing pressure as they were observed in the field.

Tables 5 and 6 also indicate that prediction of residual dry matter after grazing from height, as measured by the forage meter, was affected by the different levels of the residue left after grazing and possibly by other grazing management factors as well. Different linear regression coefficients were observed. The tendency was for the amount of residual dry matter per centimeter of height to increase with increasing amounts of residue left after grazing. Similar results have been obtained in Australia by Powell (1974) using a similar forage meter.

From coefficients of variation in Tables 5 and 6, it can be seen that about twice as many height readings with the forage meter were required than clippings in order to attain approximately the same sampling variation of individual observations. After the inclusion of the adjusted unharvested samples, the sampling variation of individual observation is about half that of the harvested samples alone. The sampling variation was about 50% diluted.

The values of the linear correlation coefficients indicate that height, as measured with the forage meter, does not correlate satisfactorily with residual dry matter after grazing. Only about 25% of the variation in residual dry matter was accounted for by height measured with the forage meter. The residue left after grazing generally lacks uniformity which results in the height measurements being less accurate. This is particularly true in overgrazed pastures where very short resi-

Fig. 9. Average residue left after grazing for the treatment where the projected residual DM was .5 metric tons/ha.

Fig. 10. Average residue left after grazing for a treatment where the projected residual DM was 1.0 metric tons/ha.

Fig. 11. Average residue left after grazing for a treatment with the intermediate grazing pressure where the projected residual DM was 1.5 metric tons/ha.

Fig. 12. Average residue left after grazing of a treatment where the projected residual DM was 2.0 metric tons/ha.

Fig. 13. Average residue left after grazing of the treatment where the projected residual DM was 2.5 metric tons/ha.

dues are left, such as was observed in the treatment where the projected residue to be left after grazing was .5 metric tons/ha of DM. The correlation between height and dry matter on offer was considerably better (not shown), the linear correlation coefficients varying from .60 to about .85. This was apparently due to the more uniform condition of the pasture.immediately before each grazing period.

From Table 6, it can be noted that, using residual dry matter as an estimator of grazing pressure, it was possible to actually impose the 20 different pre-established treatment combinations. In other words, in spite of the somewhat close proximity of expected levels of residue to be left after grazing, there was no overlapping of treatments with the same grazing and rest periods due to similarities of observed grazing pressures. Similarities in treatments having the same lengths of grazing and rest periods but with the same grazing pressure were observed by Maraschin (1975) when he used dry matter on offer as an estimator of grazing pressure. In one or two treatments with the same grazing period and rest period, but which should have had different grazing pressures, he observed that grazing pressures were so similar that those treatments were considered to be the same. This may not be inconvenient in grazing experiments set up to be analyzed by regression technique, but it would be if all treatments were replicated and the analysis did not include regression.

Total Available Dry Matter Per Cycle

Table 7A presents the effect of the treatment variables on the total available dry matter per cycle and the respective number of cycles. This total dry matter was the average estimated amount of dry matter present before and during each grazing sampled at ground level. It varied from 1.623 to 3.930 metric tons/ha.

Table 7A. Effect of treatment variables upon the total available DM per cycle—season of 182 days.

Treat. No.	Variables: Grazing Period	Rest Period	Grazing+ Pressure	Total Available DM/Cycle	No. of Cycles
	———days———		———metric tons/ha———		
1	3.5	14	.788	1.623	10
2	10.5	14	.892	2.246	7
3	3.5	42	.897	2.056	5
4	10.5	42	1.006	3.380	4
5	3.5	14	1.719	2.339	9
6	10.5	14	1.714	2.384	6
7	3.5	42	1.815	3.003	4
8	10.5	42	1.875	3.214	4
9	14.0	28	1.448	3.576	4
10	1.0	28	1.543	2.768	6
11	7.0	56	1.800	3.930	3
12	7.0	0	1.213	1.990	6
13	7.0	28	2.328	3.216	5
14	7.0	28	.413	1.856	5
15	7.0	28	1.264	2.621	5
16	7.0	28	1.410	2.991	5
17	7.0	28	1.245	2.932	5
18	7.0	28	1.341	3.012	5
19	7.0	28	1.548	2.737	5
20	7.0	42	1.409	2.986	4
21	7.0	14	1.344	1.933	8
22	7.0	28	.917	2.676	5
23	7.0	28	1.755	3.409	5
24	3.5	28	1.448	2.773	6

+Residual DM left after grazing.

The Approximating Model

The approximating model for total available dry matter per cycle was found to be

$$\hat{Y} = -.4345 + .1524X_1 + .0105X_2 + 2.2098X_3 + .0015X_1^2 - .003X_2^2$$
$$-.3633X_3^2 + .0026X_1X_2 - .1281X_1X_3 + .0107X_2X_3$$

$r^2 = .86$

Table 7B presents the analysis of variance for the model, indicating that it satisfactorily represents the response.

Table 7B. Analysis of variance of the fitted model for total available dry matter per cycle.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		.7661	9.809**
Linear		3	2.0574	26.343**
Quadratic		6	.7230	9.257**
Residual	14		.0781	
Lack-of-fit		10	.0976	3.3197 NS
Error		4	.0294	

** $P < 0.01$

Analysis of the Fitted Surface

The SP for total dry matter available per cycle was found to be located at

6 days of grazing (X_{1S})

116 days of rest (X_{2S}), and

3.7 metric tons/ha of residual DM (X_{3S}).

At that point the total dry matter available per cycle was $\hat{Y}_S = 4.7$

metric tons/ha. It is obvious that the SP does not represent satisfactory operating conditions because 116 days of rest and 3.7 metric tons of DM left after grazing are outside the experimental range of X_2 and X_3 actually used in the experiment. A residue of 3.7 metric tons/ha would, of course, be practically impossible and not feasibly obtainable under the conditions of the experiment. In addition, the response at the SP was not within the range of the responses obtained in the experiment (Table 7A).

It is necessary to study the response surface within the region of the experimental variables used in the experiment. The canonical equation

$$\hat{Y} = 4.7 + .01245W_1^2 - .00021W_2^2 - .37427W_3^2$$

and Figs. 14A and 14B indicate that the response at the SP is a minimax. It is a maximum in W_2 and W_3 and a minimum in W_1. Fig. 14B shows that moving along W_2 or W_3 away from the SP will result in less total forage available per cycle, and Fig. 14A indicates the total forage available per cycle could be increased to more than 4.7 metric tons/ha; however, this would probably not be biologically feasible.

By fixing grazing period at 6 days, for example, it can be seen from Fig. 14B that total forage available per cycle decreases by moving away from the SP along W_2 with shorter rest periods and heavier grazing pressures (or less residue left after grazing), or, in general, for a fixed grazing period, total forage available per cycle increases with less frequent grazing and lighter grazing pressures. In Fig. 14B, it is evident that movement along W_3 away from the SP has little or no biological significance since both frequency of defoliation and grazing pressure are outside the region of the experimental variables used in the experiment.

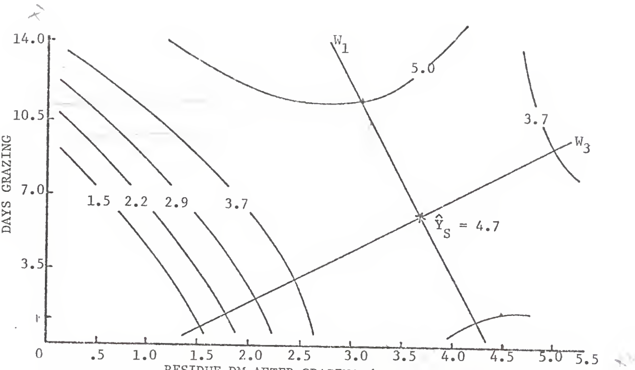


Fig. 14A. Contours of total DM available per cycle (metric tons/ha) for 116 days of rest.

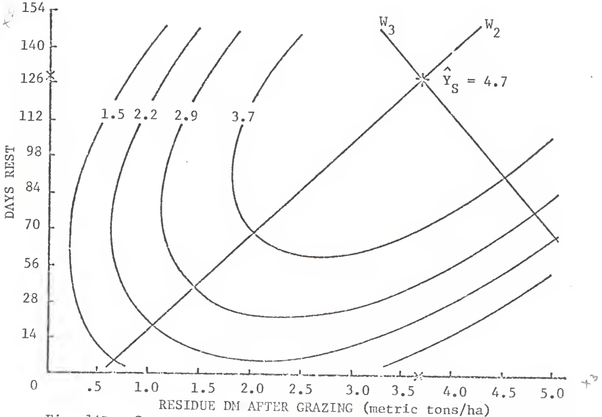


Fig. 14B. Contours of total DM available per cycle (metric tons/ha) for 6 days of grazing.

In Fig. 14A, fixing the grazing period at 116 days and varying grazing days and grazing pressure and moving away from the SP along W_3 will result in less total forage available per cycle with heavier grazing pressures and somewhat shorter grazing periods. Again, this relationship is more of an extrapolation since 116 days of rest was not used in the experiment. Movement along W_1 away from the SP results in more total forage available per cycle than 4.7 metric tons/ha but to amounts not realistically feasible under the conditions of the experiment.

Since the SP does not represent satisfactory operating conditions, the relationship between the W's and X's may indicate more desirable combinations of grazing period, rest period, and grazing pressure. It helps to determine which experimental variable should change more rapidly towards areas of more satisfactory operating conditions. The relationship was given by

$$X_1 = 6 + .9854W_1 - .0284W_2 + .16810W_3$$

$$X_2 = 116 + .0313W_1 + .9994W_2 - .0146W_3$$

$$X_3 = 3.7 + .1676W_1 + .0197W_2 + .9857W_3$$

Movement along W_1 away from the SP can be made by equating W_2 and W_3 with zero, and points along the path of steepest ascent can be obtained by substituting different values for W_1 in both directions. For example,

W_1	X_1	X_2	X_3	$\hat{Y} = 4.7 + .01245W_1^2$
-5	1	115.8	4.5	5.0
-3	3	115.9	4.2	4.8
0	6	116.0	3.7	4.7
3	9	116.1	3.2	4.8
5	11	116.2	2.9	5.0
8	14	116.3	2.4	5.5

This can also be seen in Fig. 14A.

By making W_1 and W_3 equal to zero and moving away from SP along W_2, points along the path of steepest descent are obtained. For example,

W_2	X_1	X_2	X_3	$\hat{Y} = 4.7 - .00021W_2^2$
-100	9.5	16	1.7	2.6
- 90	9.0	26	1.9	3.0
- 80	8.5	36	2.1	3.4
- 60	8.0	56	2.5	3.9
- 30	7.0	86	3.1	4.5
0	6.0	116	3.7	4.7
30	5.0	146	4.3	4.5

This relationship is also seen in Fig. 14B. It can be observed that movement along W_2 within the region of the experimental variable describes the effect of the treatments on total forage available per cycle, i.e., total forage available per cycle increases with less frequent grazing and lighter grazing pressures. This emphasizes the importance of rest period and grazing pressure, since there is little variation in days of grazing.

Other points along the path of steepest descent may be obtained moving along the axis W_3 away from the SP, making W_1 and W_2 equal to zero. For instance,

W_3	X_1	X_2	X_3	$\hat{Y} = 4.7 - .37427W_3^2$
-3.0	5.4	115.4	.7	1.3
-2.5	5.5	115.5	1.2	2.4
-2.0	5.6	115.6	1.7	3.2
-1.5	5.7	115.7	2.2	3.8
-1.0	5.8	115.8	2.7	4.3
- .5	5.9	115.9	3.2	4.6
0	6.0	116.0	3.7	4.7

The above relationship stresses the importance of grazing pressure since, for practically the same grazing period and rest period (even though rest period is outside the experimental region), the total amount of forage available per cycle increases with lighter grazing pressures, in a non-linear fashion, of course.

The format of the canonical equation suggests that maximum total forage available per cycle for fixed days of grazing can be obtained by solving $\frac{d\hat{Y}}{dX_2} = 0$ and $\frac{d\hat{Y}}{dX_3} = 0$ for X_2 and X_3 as a function of X_1. The following relation was obtained

$$X_{2S}^* = 106.27 + 1.83X_1$$

$$X_{3S}^* = 4.60 - .150X_1$$

where:

X_{2S}^* = days rest which would maximize total available forage dry matter per cycle for a given number of days grazing, and

X_{3S}^* = dry matter left after grazing which would maximize forage dry matter per cycle for a given number of days grazing.

The response is then obtained from $\hat{Y}_S^* = b_0^* + \frac{1}{2}(X_{2S}^* b_2^* + X_{3S}^* b_3^*)$

So, for say

$X_1 = 1.0,\quad X^*_{2S} = 108\quad X^*_{3S} = 4.4\quad \hat{Y}^*_S = 5.0$

$X_1 = 3.5,\quad X^*_{2S} = 112\quad X^*_{3S} = 4.0\quad \hat{Y}^*_S = 4.5$

$X_1 = 6.0,\quad X^*_{2S} = 116\quad X^*_{3S} = 3.7\quad \hat{Y}^*_S = 4.7$

$X_1 = 7.0,\quad X^*_{2S} = 119\quad X^*_{3S} = 3.5\quad \hat{Y}^*_S = 4.8$

$X_1 = 10.5,\quad X^*_{2S} = 125\quad X^*_{3S} = 3.5\quad \hat{Y}^*_S = 5.0$

$X_1 = 14.0,\quad X^*_{2S} = 132\quad X^*_{3S} = 2.5\quad \hat{Y}^*_S = 5.6$

As was seen, 6 days of grazing, 116 days of rest and 3.7 metric tons/ha DM left after grazing make up the SP. For 6 days of grazing, a maximum of 4.7 metric tons/ha of total forage DM available per cycle would require 116 days of rest and 3.7 metric tons/ha of residual DM. Of course, in this case, we have an extrapolation rather than an interpolation because the SP is remote from the experimental region. These maximums are outside the range of the experiment as can be seen in Table 7A.

Growth Rate

The pasture's average seasonal growth rate for the different treatment combinations are presented in Table 8A. It varied from 20.3 kg to 53.0 kg DM per hectare per day.

The Approximating Model

The fitted equation to approximate the growth rate response was found to be

$$\hat{Y} = 26.0370 + .8277X_1 + .0427X_2 + 14.7769X_3 + .1430X_1^2$$
$$- .0206X_2^2 - 8.0974X_3^3 + .0611X_1X_2 - 2.7088X_1X_3 + .6261X_2X_3$$

$r^2 = .70$

Table 8A. Effect of treatment variables upon the growth rate of the pasture--season average.

Treat. No.	Variables: Grazing Period	Rest Period	Grazing[+] Pressure	Growth Rate
	-------days--------		-metric tons/ha-	-kg/ha/day-
1	3.5	14	.788	39.8
2	10.5	14	.892	48.3
3	3.5	42	.897	28.2
4	10.5	42	1.006	45.5
5	3.5	14	1.719	32.7
6	10.5	14	1.714	21.2
7	3.5	42	1.815	27.8
8	10.5	42	1.875	28.0
9	14.0	28	1.448	53.0
10	1.0	28	1.543	37.3
11	7.0	56	1.800	35.0
12	7.0	0	1.213	20.3
13	7.0	28	2.328	25.6
14	7.0	28	.413	35.4
15	7.0	28	1.264	35.4
16	7.0	28	1.410	41.6
17	7.0	28	1.245	42.6
18	7.0	28	1.341	42.8
19	7.0	28	1.548	32.6
20	7.0	42	1.409	34.2
21	7.0	14	1.344	24.5
22	7.0	28	.917	42.8
23	7.0	28	1.775	43.6
24	3.5	28	1.448	38.7

[+]Residual DM left after grazing.

Table 8B presents the analysis of variance for the approximating model and shows its adequacy in representing the response.

Table 8B. Analysis of variance of the fitted model for growth rate.

Source of Variation	d.f.	M.S.	F
Total	23		
Regression	9	132.200	3.610*
Linear	3	134.961	3.686*
Quadratic	6	130.820	3.573++
Residual	14	36.617	
Lack-of-fit	10	42.456	1.928 NS
Error	4	22.020	

* $P < 0.05$

++ $P < 0.025$

Analysis of the Fitted Surface

The SP for growth rate was found at:

3.5 days grazing (X_{1S})

25 days rest (X_{2S})

1.27 metric tons/ha of residual DM (X_{3S})

The response at that point was found to be

$$\hat{Y}_S = 37.5 \text{ kg DM/ha/day}$$

and the SP is within the domain of the experimental variables used in the experiment.

The canonical form was

$$\hat{Y} = 37.5 + .3610W_1^2 - .0102W_2^2 - 8.3262W_3^2$$

and indicates that the response at the SP is a minimax. It is a maximum

in W_2 and W_3 (see also Fig. 15A), i.e., movement away from the SP along either W_2 or W_3 will result in lower growth rate than 37.5 kg/ha/day; it is a minimum in W_1 (see also Fig. 15B), i.e., movement along that axis away from the SP will result in higher growth rates than 37.5 kg/ha/day.

Fig. 15A shows that fixing the grazing period at 3.5 days and varying rest period and grazing pressure, growth rates less than 37.5 kg/ha/day will result from combinations of less frequent grazing (than 25 days) and heavier grazing pressure (than 1.2 metric tons/ha of residual DM), or more frequent grazing and lighter grazing pressures, or with more frequent grazing and heavier grazing pressures, or still with less frequent grazing and lighter grazing pressures. However, Fig. 15A indicates that growth rate is reduced more quickly by moving away from SP along W_3, i.e., for heavier grazing pressure and less frequent grazing or somewhat lighter grazing pressure and more frequent grazing.

In Fig. 15B, rest period is fixed at 25 days and grazing period and grazing pressure are varied. For that grazing frequency, growth rates higher than 37.5 kg may be obtained with heavier grazing pressures (than 1.27 metric tons/ha of residual DM) and longer grazing periods (than 3.5 days), or with shorter grazing period and slightly lighter grazing pressures within the actual region of the independent variables. It can be seen from Fig. 15B that more appreciable increases in growth rate can be obtained with heavier grazing pressures and longer grazing periods.

For growth rate, the relationship between the canonical variables (W's) and the actual variables (X's) was given by

$$X_1 = 3.5 + .9858W_1 + .0574W_2 + .1579W_3$$

$$X_2 = 25 - .0520W_1 + .9977W_2 - .0377W_3$$

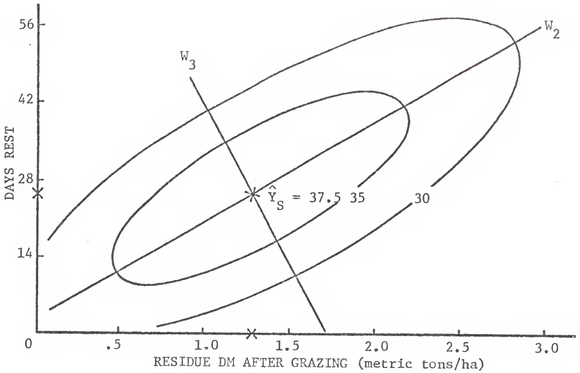


Fig. 15A. Contours of growth rate (kg DM/ha/day) for 3.5 days of grazing.

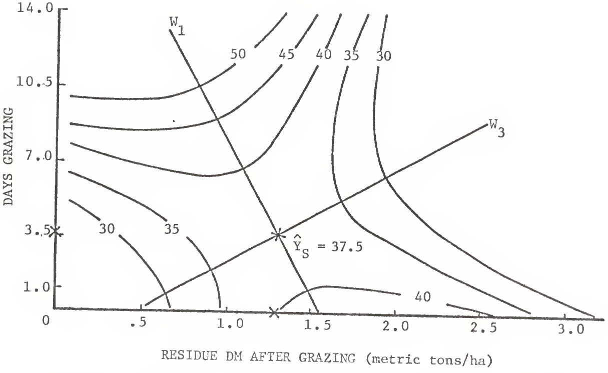


Fig. 15B. Contours of growth rate (kg DM/ha/day) for 25 days of rest.

$$X_3 = 1.27 - .1598W_1 + .0290W_2 + .9867W_3$$

In order to obtain combinations of grazing period, rest period, and grazing pressure which will result in pasture growth rates per hectare per day higher than 37.5 kg, W_2 and W_3 must be equal to zero and W_1 given different values in both directions away from the SP. So,

W_1	X_1	X_2	X_3	$\hat{Y} = 37.5 + .3610W_1^2$
-2.5	1.0	25.2	1.67	39.7
-1.5	2.0	25.1	1.51	38.3
0	3.5	25.0	1.27	37.5
1.5	5.0	24.9	1.00	38.3
2.5	6.0	24.8	.87	39.7
3.5	7.0	24.7	.71	41.9
4.5	8.0	24.6	.55	44.8

It is seen that approximately 25 days rest are necessary for obtaining growth rates equal to or higher than 37.5 kg. For higher growth rates, grazing pressure and grazing period run simultaneously in opposite directions. However, much higher growth rates may be attained, within the experimental region, with heavier grazing pressures and longer grazing periods.

Points along the path of steepest descent can be obtained either by making W_1 and W_3 equal to zero and substituting different values of W_2, or by making W_1 and W_2 equal to zero and assigning different values to W_3. For the former case, for example,

W_2	X_1	X_2	X_3	$\hat{Y} = 37.5 - .0102W_2^2$
-10	3.0	15	.98	36.5
- 5	3.2	20	1.12	37.2
0	3.5	25	1.27	37.5
5	3.7	30	1.42	37.2
10	4.0	35	1.56	36.5
15	4.3	40	1.70	35.2
20	4.5	45	1.85	33.4
25	4.7	50	2.00	31.1

or for the latter case,

W_3	X_1	X_2	X_3	$\hat{Y} = 37.5 - 8.3262W_3^2$
-.75	3.3	25.2	.53	32.8
-.50	3.4	25.1	.78	35.4
0	3.5	25.0	1.27	37.5
.50	3.7	24.9	1.76	35.4
.75	3.8	24.8	2.00	32.8

Again, since the response at the SP is a maximum in W_2 and W_3, maximum responses for fixed days of grazing can be predicted by solving $\frac{d\hat{Y}}{dX_2} = 0$ and $\frac{d\hat{Y}}{dX_3} = 0$ for X_2 and X_3 as a function of X_1. The following relation was obtained

$$X_{2S}^* = 34.5053 - 2.4561X_1$$

$$X_{3S}^* = 2.2464 - .2622X_1$$

The predicted maximum growth rate of the pasture for different days of grazing is obtained from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}\,(X_{2S}^* b_2^* + X_{3S}^* b_3^*)$$

Let us say, for

$X_1 = 1.0,\quad X^*_{2S} = 32.0\quad X^*_{3S} = 1.98\quad \hat{Y}^*_S = 40.6$

$X_1 = 3.5,\quad X^*_{2S} = 25.0\quad X^*_{3S} = 1.27\quad \hat{Y}^*_S = 37.5$

$X_1 = 7.0,\quad X^*_{2S} = 19.5\quad X^*_{3S} = .70\quad \hat{Y}^*_S = 42.0$

So, for example, for 1 day grazing, a predicted maximum growth rate of approximately 40.5 kg of DM per hectare per day may be obtained with approximately 32 days rest and 1.98 metric tons/ha of DM left after grazing. Of course, 3.5 days grazing, 25 days rest, and 1.27 metric tons/ha of residual DM comprise the SP and the maximum growth rate at that point is 37.5 kg. For 7 days grazing, a maximum average growth rate of 42.0 kg can be accomplished with approximately 20 days rest and .70 metric tons/ha of residual DM.

The above relationship indicates that, in order to maximize growth rate for a given number of grazing days, different grazing pressures require different numbers of days rest. Here again, it is clear that growth rates higher than 37.5 kg can be obtained with fewer days grazing (than 3.5), longer rest periods (than 25) but lighter grazing pressures (than 1.27 metric tons/ha of residual DM), or with longer grazing periods (than 3.5 days), shorter rest periods (than 25 days), and heavier grazing pressures (than 1.27 metric tons/ha of residual DM). This relationship can also be noted by observing Table 8A.

Total Net Dry Matter

Table 9A presents the season total net dry matter yield for the different treatment combinations. Total net dry matter varied from 4.057 to 9.149 metric tons/ha. This response variable represents the actual production of the pasture. Total net dry matter yield represents the summation of all cycles of the dry matter produced during the rest period and the grazing period in each cycle.

Table 9A. Effect of treatment variables upon net DM yield--season total, 182 days.

Treat. No.	Grazing Period	Rest Period	Grazing+ Pressure	Net DM Yield
	---------days---------		----metric tons/ha-----	
1	3.5	14	.788	7.563
2	10.5	14	.892	8.903
3	3.5	42	.897	5.351
4	10.5	42	1.006	9.149
5	3.5	14	1.719	5.860
6	10.5	14	1.714	4.057
7	3.5	42	1.815	5.044
8	10.5	42	1.875	5.860
9	14.0	28	1.448	8.121
10	1.0	28	1.543	7.158
11	7.0	56	1.800	6.633
12	7.0	0	1.213	4.119
13	7.0	28	2.328	5.387
14	7.0	28	.413	6.119
15	7.0	28	1.264	6.792
16	7.0	28	1.410	7.678
17	7.0	28	1.245	8.098
18	7.0	28	1.341	8.105
19	7.0	28	1.548	6.210
20	7.0	42	1.409	6.091
21	7.0	14	1.344	4.404
22	7.0	28	.917	8.017
23	7.0	28	1.775	8.607
24	3.5	28	1.448	7.588

+Residual DM left after grazing.

Since growth rate of the pasture was used in the estimation of net dry matter, it is expected that they have similar responses.

The Approximating Model

The fitted equation to approximate net dry matter production was

$$\hat{Y} = 4.6698 + .2660X_1 - .0117X_2 + 2.9935X_3 + .0080X_1^2$$
$$- .0037X_2^2 - 1.4333X_3^2 + .0147X_1X_2 - .4916X_1X_3 + .1066X_2X_3$$
$$r^2 = .62$$

The analysis of variance for approximating model is presented in Table 9B. The non-significant lack-of-fit indicates that the model is satisfactory to represent the response.

Table 9B. Analysis of variances of the fitted model for total net dry matter production.

Source of Variation	d.f.	M.S.	F
Total	23		
Regression	9	3.6339	2.5484*
Linear	3	3.2707	2.3078 NS
Quadratic	6	3.8154	2.6758+
Residual	14	1.4259	
Lack-of-fit	10	1.7119	2.407 NS
Error	4	.7111	

* $P < 0.05$

\+ $P < 0.075$

Analysis of the Fitted Surface

The SP for total net dry matter production was found to be at

3.5 days grazing (X_{1S})

25.5 days rest (X_{2S})

1.4 metric tons/ha of residual DM (X_{3S})

The total net dry matter at that point was

$$\hat{Y}_S = 7.1 \text{ metric tons/ha}$$

and, as was the case for growth rate, the SP is well within the experimental region of the experimental variables.

The canonical equation

$$\hat{Y} = 7.1 + .04488W_1^2 - .0018W_2^2 - 1.4760W_3^2$$

indicates that the net dry matter yield at the SP is a minimax. Movement along W_2 and W_3 away from the SP will result in less net dry matter per hectare than 7.1 metric tons, whereas movement along W_1 away from the SP will result in higher net dry matter than that at the SP. These relationships are also seen in Fig. 16A and Fig. 16B.

Fixing grazing period at 3.5 days (Fig. 16A) and moving along W_3 away from the SP will result in lower net dry matter production than 7.1 metric tons/ha, either with longer rest periods (than 25.5 days) and heavier grazing pressure (than 1.4 metric tons/ha of residual DM) or shorter rest periods associated with lighter grazing pressures. Movement along W_2 away from the SP will also result in lower net dry matter either with more frequent grazing associated with heavy grazing pressures or less frequent defoliation associated with lighter grazing pressures. For the same unit change, movement along W_3 will reduce net dry matter (from 7.1 metric tons/ha) faster than movement along W_2. Of course, it is seen that, for 3.5 days grazing, the total net dry matter at the SP is at a local maximum.

If rest period is fixed at 25.5 days (Fig. 16B), movement along W_1 in either direction away from the SP will result in higher net dry matter yields (than 7.1 metric tons/ha). However, it appears that

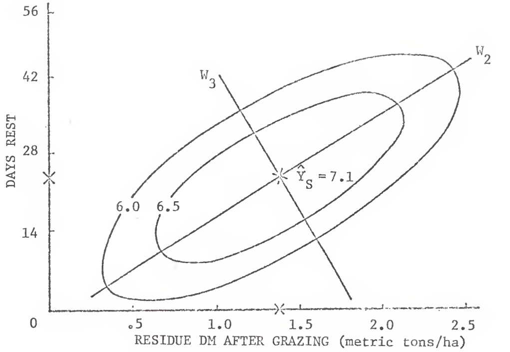


Fig. 16A. Contours of net DM production (metric tons/ha) for 3.5 days of grazing.

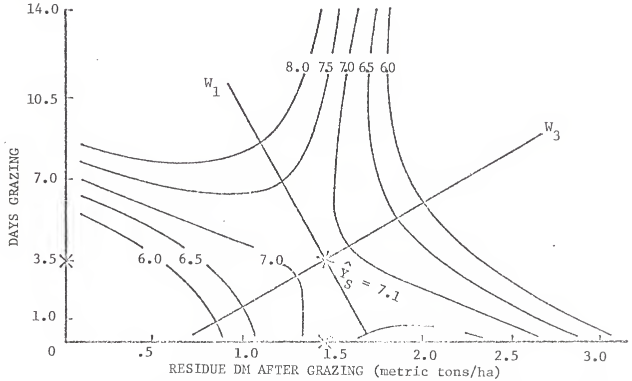


Fig. 16B. Contours of net DM production (metric tons/ha) for 25 days of rest.

W_2	X_1	X_2	X_3	$\hat{Y} = 7.1 - .0018W_2^2$
-10	3.0	15.5	1.00	6.92
- 5	3.3	20.5	1.24	7.05
0	3.5	25.5	1.40	7.10
5	3.8	30.5	1.56	7.05
10	4.0	35.5	1.70	6.92
15	4.3	40.5	1.87	6.70

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = 7.1 - 1.4760W_3^3$
-1	3.3	25.6	.41	5.60
0	3.5	25.5	1.40	7.10
1	3.7	25.4	2.38	5.60

Those changes along W_2 and W_3 may also be visualized in Fig. 16A and Fig. 16B, respectively.

The canonical form indicates that maximum responses for fixed values of grazing periods can be predicted by solving $\frac{d\hat{Y}}{dX_2} = 0$ and $\frac{d\hat{Y}}{dX_3} = 0$ for X_2 and X_3 as a function of X_1. The following relationships were found:

$$X_{2S}^* = 34.5053 - 2.4561X_1$$

$$X_{3S}^* = 2.2464 - .2622X_1$$

Predicted maximum total net dry matter yields for fixed number of grazing days can be obtained from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}(X_{2S}^* b_2^* + X_{3S}^* b_3^*)$$

So, for example, for

$X_1 = 1.0,$	$X_{2S}^* = 28.0$	$X_{3S}^* = 1.95$	$\hat{Y}_S^* = 7.42$
$X_1 = 3.5,$	$X_{2S}^* = 25.5$	$X_{3S}^* = 1.40$	$\hat{Y}_S^* = 7.10$
$X_1 = 7.0,$	$X_{2S}^* = 22.0$	$X_{3S}^* = .70$	$\hat{Y}_S^* = 7.76$

These maximums for fixed grazing days also illustrate the path of steepest ascent which can be visualized in Fig. 16B. If the response at the SP is not satisfactory, other combinations may be obtained which may give local maximums or not. Some of the responses along the paths of steepest ascent or descent can be approximately located in Table 9A.

Stocking Rate (Animals per Hectare per Day)

The effects of the different combinations on the average number of animals per hectare per day are presented in Table 10A. Animals per hectare per day varied from 3.4 to 10.5. The season average weight of the animals was 345 kg.

The Approximating Model

The fitted equation to approximate the number of animals per hectare per day was found to be

$$\hat{Y} = 15.0689 - .6563X_1 + .0448X_2 - 5.5873X_3 + .0218X_1^2 - .0046X_2^2 - .1109X_3^2 + .0092X_1X_2 - .0589X_1X_3 + .1152X_2X_3$$

$$r^2 = .86$$

The analysis of variance for the model is presented in Table 10B which shows (by the non-significant lack-of-fit) that the model satisfactorily represents the response.

Analysis of the Fitted Surface

The location of the SP for animals per hectare per day was found at

7.5 days grazing (X_{1S})

60 days rest (X_{2S})

3.8 metric tons/ha of residual DM (X_{3S})

where $\hat{Y}_S$ = 3.3 animals/ha/day. It can be seen that the SP is outside

Table 10A. Effect of treatment variables upon stocking rate expressed as the number of animals per hectare per day--season average.

Treat. No.	Grazing Period	Rest Period	Grazing+ Pressure	Animals/ha/day
	--------days--------		-metric tons/ha-	
1	3.5	14	.788	10.0
2	10.5	14	.892	7.0
3	3.5	42	.897	6.2
4	10.5	42	1.006	6.0
5	3.5	14	1.719	6.3
6	10.5	14	1.714	4.3
7	3.5	42	1.815	5.4
8	10.5	42	1.875	4.3
9	14.0	28	1.448	7.0
10	1.0	28	1.543	8.5
11	7.0	56	1.800	4.5
12	7.0	0	1.213	3.7
13	7.0	28	2.328	3.4
14	7.0	28	.413	10.5
15	7.0	28	1.264	6.5
16	7.0	28	1.410	7.1
17	7.0	28	1.245	7.8
18	7.0	28	1.341	6.8
19	7.0	28	1.548	6.0
20	7.0	42	1.409	7.2
21	7.0	14	1.344	5.2
22	7.0	28	.917	9.0
23	7.0	28	1.775	6.6
24	3.5	28	1.448	7.5

+Residual DM left after grazing.

Table 10B. Analysis of variance of the fitted model for animals per hectare per day.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		7.3881	9.595**
Linear		3	14.5616	18.911**
Quadratic		6	3.8013	4.937**
Residual	14		.7700	
Lack-of-fit		10	.8969	1.977 NS
Error		4	.4530	

* P < 0.01

the experimental region with relation to rest period and grazing pressure. On the other hand, $\hat{Y}_S$ at that combination is slightly below the minimum stocking rate observed in the experiment.

The canonical form

$$\hat{Y} = 3.3 + .0319W_1^2 + .0156W_2^2 - .1413W_3^2$$

indicates that the system is a minimax. Movement along W_1 and W_2 away from the SP will result in higher stocking rate, and movement along W_3 will result in lower stocking rate. Fig. 17A and Fig. 17B show these relationships. In Fig. 17A, the grazing period is fixed at 7.5 days. The system is a falling ridge because the response decreases with movement along W_2 towards the SP which is located outside the experimental region of the independent variables used in the experiment. For 7.5 days of grazing, animals per hectare per day increases with shorter rest periods and heavier grazing pressures. This can also be clearly seen in Table 10A.

Fig. 17B indicates that, when the rest period is fixed at 60 days

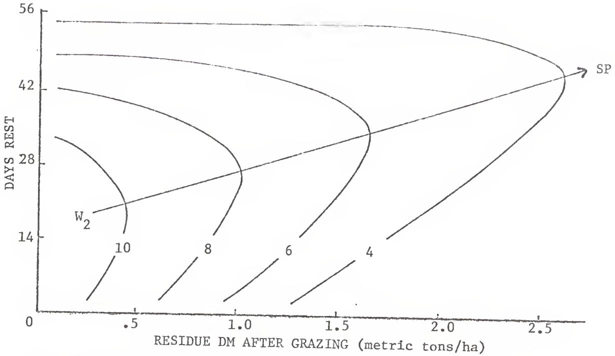


Fig. 17A. Contours of animals/ha/day for 7.5 days of grazing.

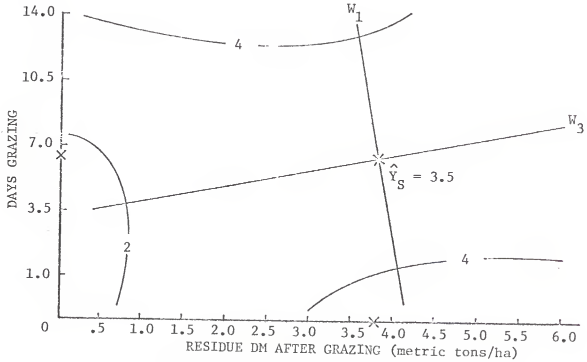


Fig. 17B. Contours of animals/ha/day for 60 days of rest.

and changes are made along W_1 away from the SP, small increases in the number of animals per hectare per day are obtained with slightly heavier grazing pressures (still outside the experimental region) and longer grazing periods. Fig. 17B also indicates that the number of animals per hectare per day may be slightly reduced with very long rest periods and shorter days of grazing, even with heavier grazing pressures. This reduction, however, is insignificant and such small stocking rate (2 animals/ha/day) was not observed in the experiment.

The relationship between the canonical variables and the actual variables is given by

$$X_1 = 7.5 + .8203W_1 + .5447W_2 + .1744W_3$$
$$X_2 = 60 - .4513W_1 + .8038W_2 - .3876W_3$$
$$X_3 = 3.8 - .3512W_1 + .2392W_2 + .8052W_3$$

Stocking rates may be obtained for points along the path of steepest ascent moving along W_1 and W_2. For example, along W_1

W_1	X_1	X_2	X_3	$\hat{Y} = 3.3 + .03189W_1^2$
9.5	15.5	55.0	.46	6.2
9.0	15.0	55.5	.64	5.9
8.0	14.0	56.0	1.00	5.3
5.0	11.5	57.0	2.00	4.1
0	7.5	60.0	3.80	3.3
-5.0	3.5	62.0	5.50	4.1

or along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = 3.3 + .01562W_2^2$
-12.5	1.0	49.0	.80	5.7
-10.0	2.0	51.5	1.40	4.9
- 5.0	5.0	55.5	2.60	3.7
0	7.5	60.0	3.80	3.3
5.0	9.0	64.5	5.00	3.7

It can be seen that, within the region of the experimental variables used in the experiment, the number of animals per hectare per day increases (from the SP) with more frequent grazing and heavier grazing pressure (with longer grazing periods moving along W_1, and shorter grazing periods moving along W_2).

It appears to be of no interest to look at the path of steepest descent, since stocking rates would be less than the minimum observed in the experiment.

Stocking Rate
(Liveweight per Hectare per Day)

Like animals per hectare per day, liveweight per hectare per day was used as an estimator of the stocking rate necessary to attain the desired grazing pressure for each combination of grazing period and rest period, and , in the context of the response surface analysis, was used as response variable.

Table 11A presents the average stocking rates in terms of liveweight per hectare per day for each treatment combination. It varied from 1.146 to 3.359 metric tons/ha/day.

Table 11A. Effect of treatment variables upon average stocking rate expressed as liveweight per hectare per day.

Treat. No.	Variables: Grazing Period	Variables: Rest Period	Variables: Grazing+ Pressure	LW/ha/day
	--------days--------		-metric tons/ha-	-metric tons-
1	3.5	14	.788	3.359
2	10.5	14	.892	2.398
3	3.5	42	.897	2.089
4	10.5	42	1.006	2.100
5	3.5	14	1.719	2.144
6	10.5	14	1.714	1.320
7	3.5	42	1.815	1.930
8	10.5	42	1.875	1.461
9	14.0	28	1.448	2.538
10	1.0	28	1.543	2.900
11	7.0	56	1.800	1.542
12	7.0	0	1.213	1.184
13	7.0	28	2.328	1.146
14	7.0	28	.413	3.100
15	7.0	28	1.264	2.188
16	7.0	28	1.410	2.403
17	7.0	28	1.245	2.573
18	7.0	28	1.341	2.271
19	7.0	28	1.548	2.087
20	7.0	42	1.409	2.192
21	7.0	14	1.344	1.465
22	7.0	28	.917	2.950
23	7.0	28	1.775	2.229
24	3.5	28	1.448	2.422

+Residual DM left after grazing.

The Approximating Model

The fitted model for liveweight per hectare per day was

$$\hat{Y} = 4.8764 - .2652X_1 + .0096X_2 - 1.4618X_3 + .0117X_1^2 - .0016X_2^2$$
$$- .1620X_3 + .0033X_1X_2 - .03525X_1X_3 + .0432X_2X_3$$
$$r^2 = .86$$

The analysis of variance for the fitted model is presented in Table 11B, and the non-significant lack-of-fit indicates that the model represents the response satisfactorily.

Table 11B. Analysis of the variance of the fitted model for liveweight per hectare per day.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		.7801	9.977**
Linear		3	1.3187	16.863**
Quadratic		6	.5108	6.532**
Residual	14		.0782	
Lack-of-fit		10	.0951	2.648 NS
Error		4	.0359	

** $P < 0.01$

Analysis of the Fitted Surface

The analysis of the response surface indicates that the SP for liveweight per hectare per day was found to be at

7.5 days grazing (X_{1S})

75 days rest (X_{2S})

4.6 metric tons/ha of residual DM (X_{3S}),

and the amount of liveweight per hectare per day at that point was $\hat{Y}_S$ =

.82 metric tons. It can be seen that days rest and grazing pressure are located outside the experimental region of the independent variables used in the experiment. Under the conditions of the experiment, 4.6 metric tons/ha of residual DM could not be observed (compare with average total forage dry matter on offer per cycle in Table 7A). On the other hand, .82 metric tons of liveweight/ha/day was less than the minimum observed in the experiment (Table 11A). Therefore, the location of and the response at the SP do not represent satisfactory operating conditions. Consequently, it is necessary to look at the response surface within the region of the experimental variables used in the experiment.

The canonical equation

$$\hat{Y} = .82 + .0135W_1^2 + .0013W_2^2 - .1666W_3^2$$

says that the amount of liveweight per hectare per day at the SP is a minimax. It may be increased with movements along W_1 and W_2 away from the SP and reduced with movement away from SP along W_3. Figures 18A and 18B show these relationships.

Fig. 18A indicates that, when the number of grazing days is fixed at 7.5, a falling ridge system exists, i.e., the amount of liveweight per hectare per day decreases with movement along W_2 toward the SP which is outside the region of the experiment. Fig. 18A clearly indicates that, moving away from the SP along W_2, liveweight per hectare per day has to be increased with heavier grazing pressures and more frequent grazing. Moving along the W_2 ridge toward the SP, the reciprocal is evident, i.e., average liveweight per hectare per day has to decline with longer rest periods and more residue dry matter left after grazing. Therefore, Fig. 18A clearly demonstrates the effect of rest period and grazing pressure on the stocking rate.

If the rest period is fixed at 75 days (Fig. 18B) and the grazing

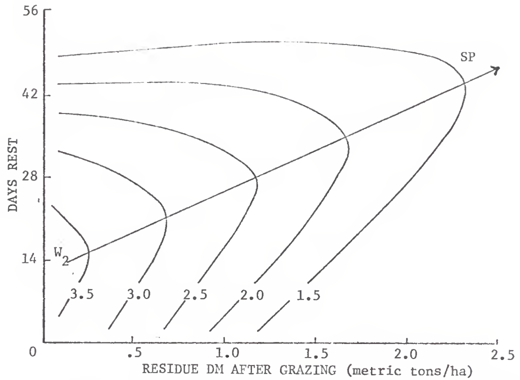


Fig. 18A. Contours of liveweight/ha/day (metric tons) for 7.5 days of grazing.

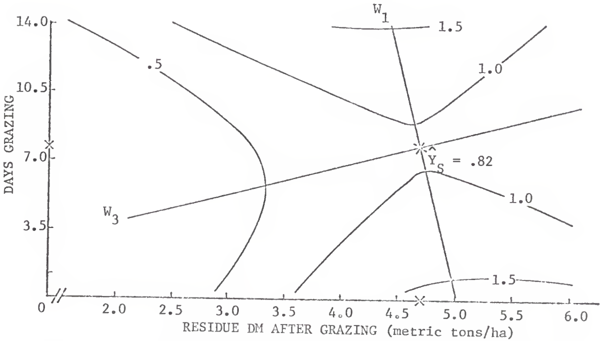


Fig. 18B. Contours of liveweight/ha/day (metric tons) for 75 days of rest.

period and grazing pressure are varied, by moving along W_1 away from the SP, liveweight per hectare per day may be increased. However, the increase with longer grazing period and heavier grazing pressure is very small. Besides, grazing pressure is still outside the experimental region. Notwithstanding, this indicates that grazing period has some effect on the stocking rate necessary to obtain a given grazing pressure at a given rest period. In Fig. 18B, it can also be visualized that, for long rest periods such as 75 days, movement along W_3 away from the SP (remote from the experimental region) toward the experimental region of the independent variables has little effect on the response. Besides, it would involve extrapolation which should be avoided since both rest period and grazing pressure would still fall outside the experimental region.

Therefore, Fig. 18A is really the best pictorial representation of the response surface of liveweight per hectare per day.

The relationship between W's and X's is given by

$$X_1 = 7.5 + .9936W_1 + .0539W_2 + .0987W_3$$
$$X_2 = 75 - .0408W_1 + .9906W_2 - .1302W_3$$
$$X_3 = 4.6 - .1048W_1 + .1254W_2 + .9866W_3$$

and points along the path of steepest ascent may be obtained along W_1 and W_2, making W_2 and W_3 or W_1 and W_3 equal zero, respectively. For instance, along W_1,

W_1	X_1	X_2	X_3	$\hat{Y} = .82 + .01350W_1^2$
7	14.5	74.8	3.90	1.50
5	12.5	74.9	4.10	1.16
0	7.5	75.0	4.60	.82

and along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = .82 + .00125X_2^2$
-35	5.0	40	.25	2.35
-30	5.5	45	.83	1.95
-25	6.0	50	1.46	1.60
-20	6.5	55	2.10	1.32
0	7.5	75	4.60	.82

Again, it is seen that movement along W_2 away from the SP (see also Fig. 18A) clearly indicates the nature of this response.

Movement along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = .82 - .16659W_3^2$
4	8.0	74.5	8.5	-1.84
3	7.7	74.7	7.6	- .68
0	7.5	75.0	4.6	.82
-3	7.3	75.2	1.6	- .68
-4	7.0	75.5	.6	-1.84

adds little to the interpretation of the response surface of liveweight per hectare per day as it was discussed above.

The format of the canonical equation and the location of the SP suggests that maximum liveweight per hectare per day for some grazing systems (combinations of grazing periods and rest periods) may be predicted by solving $\frac{d\hat{Y}}{dX_3} = 0$ for X_3 as a function of X_1 and X_2; the following relationship was obtained

$$X_{3S}^{*} = -4.5 - .109X_1 + .133X_2$$

Predicted maximum stocking rates for some fixed combination of grazing periods and rest periods may be obtained from

$$\hat{Y}^*_S = b^*_0 + \frac{1}{2}(X^*_{3S}b^*_3)$$

For example, for

$X_1 = 1.0$	$X_2 = 42,$	$X^*_{3S} = .98$	$\hat{Y}^*_S = 2.5$
$X_1 = 1.0$	$X_2 = 56,$	$X^*_{3S} = 2.80$	$\hat{Y}^*_S = 1.6$
$X_1 = 3.5$	$X_2 = 42,$	$X^*_{3S} = .70$	$\hat{Y}^*_S = 2.2$
$X_1 = 3.5$	$X_2 = 56,$	$X^*_{3S} = 2.50$	$\hat{Y}^*_S = 1.3$
$X_1 = 7.0$	$X_2 = 42,$	$X^*_{3S} = .32$	$\hat{Y}^*_S = 2.1$
$X_1 = 7.0$	$X_2 = 56,$	$X^*_{3S} = 2.20$	$\hat{Y}^*_S = 1.2$
$X_1 = 10.5$	$X_2 = 56,$	$X^*_{3S} = 1.80$	$\hat{Y}^*_S = 1.4$
$X_1 = 14.0$	$X_2 = 56,$	$X^*_{3S} = 1.40$	$\hat{Y}^*_S = 1.9$

Dry Matter on Offer per 100 kg of Body Weight per Day

Table 12A shows the amount of dry matter on offer per 100 kg of body weight as affected by the treatment combinations of days grazing, days rest and grazing pressure. It varied from 1.5 to 7.1 kg. The minimum observed was below the pre-established minimum (3.33 kg) and the maximum below the pre-established maximum (8.67 kg) which were used as first approximations for stocking the pastures to obtain the desired grazing pressures after adjusting the grazing animals. Therefore, DMO/100 kg BW/day was analyzed as a response variable.

The Approximating Model

The approximating model relating days grazing, days rest and grazing pressure to dry matter on offer per 100 kg body weight was

$$\hat{Y} = 2.0878 + .2243X_1 - .0756X_2 + .5965X_3 - .0211X_1^2 + .0020X_2$$
$$+ 1.0366X_3 - .0030X_1X_2 + .1387X_1X_3 - .0568X_2X_3$$

Table 12A. Effect of treatment variables upon the average amount of DM on offer per 100 kg of body weight per day.

Treat. No.	Variables			DM_0%/day++
	Grazing Period	Rest Period	Grazing+ Pressure	
	-------days-------		-metric tons/ha-	---kg-----
1	3.5	14	.788	2.6
2	10.5	14	.892	3.3
3	3.5	42	.897	2.4
4	10.5	42	1.006	1.7
5	3.5	14	1.719	5.7
6	10.5	14	1.714	6.1
7	3.5	42	1.815	3.4
8	10.5	42	1.875	4.3
9	14.0	28	1.448	2.8
10	1.0	28	1.543	2.5
11	7.0	56	1.800	4.0
12	7.0	0	1.213	5.6
13	7.0	28	2.328	7.1
14	7.0	28	.413	1.5
15	7.0	28	1.264	3.3
16	7.0	28	1.410	3.3
17	7.0	28	1.245	3.0
18	7.0	28	1.341	3.4
19	7.0	28	1.548	3.8
20	7.0	42	1.409	2.7
21	7.0	14	1.344	4.1
22	7.0	28	.917	2.1
23	7.0	28	1.775	4.5
24	3.5	28	1.448	3.5

+ Residual DM left after grazing.

++ DM on offer per 100 kg of body weight per day.

$r^2 = .96$

The very high r^2 value suggests that almost all variation in dry matter on offer per 100 kg body weight is accounted for the variation in the experimental variables. This, of course, was an expected relationship.

The testing of the fitted model is presented in the analysis of variance in Table 12B. The non-significant lack-of-fit indicates the appropriateness of the model.

Table 12B. Analysis of variance of the fitted model for dry matter on offer per 100 kg body weight per day.

Sources of Variation	d.f.		M.S.	F
Total	23			
Regression	9		4.9513	38.198**
Linear		3	12.3697	95.445**
Quadratic		6	1.2421	9.584**
Residual	14		.1296	
Lack-of-fit		10	.1483	1.786 NS
Error		4	.0830	

$**P < 0.01$

Analysis of the Fitted Surface

The analysis of the response surface indicates that the SP was found to be a combination of

4 days grazing (X_{1S})

23 days of rest (X_{2S})

.10 metric tons/ha of residual DM (X_{3S})

and $\hat{Y}_S = 1.7$ kg of DM_0/100 kg BW/day which represents, of course, an ex-

tremely overgrazed situation. Even though days grazing and days rest are well within the experimental region, .10 metric tons/ha of DM left after grazing is practically impossible to obtain and the grazing animals would certainly be under a starving condition. So, the SP does not represent satisfactory operating conditions.

Satisfactory operating conditions may be attained by exploring the response surface within the region of the independent variables actually used in the experiment. The canonical form from this response variable was

$$\hat{Y} = 1.7 - .0256W_1^2 + .0012W_2^2 + 1.0419W_3^2$$

and indicates a minimax type of response. It suggests that, moving away from the SP, dry matter on offer per 100 kg body weight per day increases along W_2 and W_3 and declines along W_1. Fig. 19A and Fig. 19B illustrate these relationships.

Fig. 19A shows that, fixing the grazing period at 4 days and varying rest period and grazing pressure, moving along W_2 away from the SP, the response increases with less frequent grazing and more lenient grazing pressures. Movement along W_3 in Fig. 19A adds very little to the exploration of the response surface except that, for fixed days of grazing, slightly lighter grazing pressures associated with less frequent grazing tend to cause some increase in dry matter on offer per 100 kg body weight per day.

In Fig. 19B, rest period is fixed at 23 days and days grazing and grazing pressure are varied. Here, moving along W_3 emphasizes the importance of grazing pressure. Less residue dry matter results in less dry matter on offer per 100 kg body weight per day, or moving along W_3 away from the SP propitiates more feed available per animal per day and this is even slightly increased by longer grazing periods. Movement along

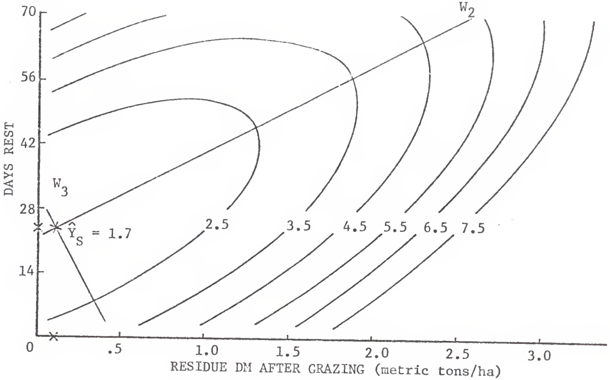


Fig. 19A. Contours of DM offer per 100 kg body weight per day (kg) for 4 days of grazing.

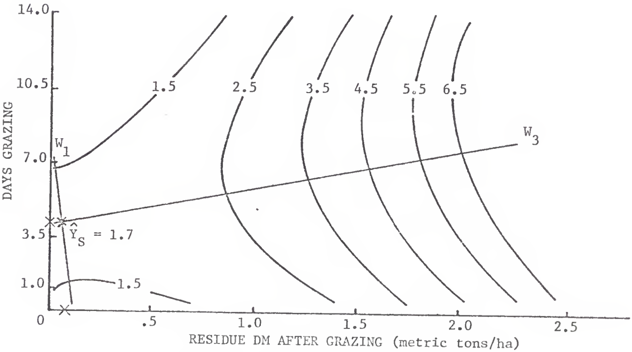


Fig. 19B. Contours of DM on offer per 100 kg body weight per day (kg) for 23 days of rest.

W_1 away from the SP adds little information for describing the response surface of the parameter in question, especially because it involves extremely overgrazed situations not included in the experiment.

It is clear, then, that grazing pressure (primarily), rest period, and, to a lesser extent, grazing period influence the amount of daily dry matter on offer per unit body weight in a grazing experiment.

Since the SP does not represent a satisfactory set of operating conditions, the relationship between the W's and the X's,

$$X_1 = 4 + .9978W_1 + .0138W_2 + .0651W_3$$
$$X_2 = 23 - .0121W_1 + .9996W_2 - .0274W_3$$
$$X_3 = .10 - .0654W_1 + .0265W_2 + .9975W_3$$

may indicate, without consideration as to other response variables, more desirable sets of operating conditions along the path of steepest ascent, within the domains of the experiment, since the response at the SP is at a minimum.

Setting W_1 and W_3 equal to zero and moving along W_2 away from the SP, points may be obtained such as,

W_2	X_1	X_2	X_3	$\hat{Y} = 1.7 + .0012W_2^2$
0	4.0	23	.10	1.70
5	4.1	29	.25	1.73
10	4.2	34	.36	1.80
20	4.5	44	.63	2.20
30	4.7	54	.90	2.80
40	4.8	64	1.10	3.60

or moving alone W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = 1.7 + 1.0419W_3^2$
0	4.0	23.0	.10	1.7
1.0	4.1	22.9	1.10	2.7
1.5	4.1	22.8	1.56	4.0
2.0	4.3	22.7	2.10	5.8
2.5	4.4	22.5	2.60	8.2

The above relationships are also apparent in Fig. 19A and Fig. 19B.

Movement along W_1 away from the SP reduces results in even less dry matter on offer per 100 kg body weight than that observed in the experiment (Table 12A) and becomes of no practical significance under these circumstances.

Based on the format of the canonical form and the location of the SP, predicted number of grazing days for fixed combinations of rest periods and grazing pressures which will maximize daily dry matter on offer per 100 kg body weight may be obtained by solving the equation $\frac{d\hat{Y}}{dX_1} = 0$ for X_1 as a function of X_2 and X_3, as follows:

$$X_{1S}^{*} = 5.333 - .0714X_2 + 3.309X_3$$

The predicted maximums may be obtained from the formula

$$\hat{Y}_S^{*} = b_0^{*} + \frac{1}{2}\,(X_{1S}b_1^{*})$$

For example, for

$X_2 = 28$	$X_3 = .5,$	$X_{1S}^{*} = 5.0$	$\hat{Y}_S^{*} = 1.8$
$X_2 = 28$	$X_3 = 1.0,$	$X_{1S}^{*} = 7.0$	$\hat{Y}_S^{*} = 2.5$
$X_2 = 28$	$X_3 = 1.5,$	$X_{1S}^{*} = 8.5$	$\hat{Y}_S^{*} = 3.9$
$X_2 = 28$	$X_3 = 2.0,$	$X_{1S}^{*} = 10.5$	$\hat{Y}_S^{*} = 5.8$
$X_2 = 28$	$X_3 = 2.5,$	$X_{1S}^{*} = 12.0$	$\hat{Y}_S^{*} = 8.3$
$X_2 = 28$	$X_3 = 1.5,$	$X_{1S}^{*} = 9.0$	$\hat{Y}_S^{*} = 4.1$

$X_2 = 42 \qquad X_3 = 1.5, \qquad X_{1S}^* = 7.0 \qquad Y_S^* = 3.3$

$X_2 = 56 \qquad X_3 = 1.5, \qquad X_{1S}^* = 6.0 \qquad Y_S^* = 3.5$, etc.

Physiologically Active Grass Percentage

This component of the pasture mixture corresponds to the hand-separated green grass, free of dried, decayed and decaying biomass and sand. The observed physiologically active grass, as seen in Table 13A, varied from 45.4 to 83.6%. In the pasture mixture, the grass component, in terms of dry matter contribution, was the most predominant in 1975.

The Approximating Model

After the actual percentages of physiologically active grass component were transformed to arcsine in an attempt to avoid heterogeneity of variances, the fitted model was found to be

$$\hat{Y} = .7042 + .0112X_1 + .0197X_2 + .1298X_3 + .0002X_1^2 - .003X_2^2$$
$$-.0051X_3^2 + .003X_1X_2 - .0155X_1X_3 - .0029X_2X_3$$
$$r^2 = .90$$

The model was tested (Table 13B) and was proved to be satisfactorily appropriate to describe this particular response surface as indicated by the nonsignificant lack-of-fit.

Analysis of the Fitted Surface

For this response variable, the SP was located at

2 days of grazing (X_{1S})

28 days of rest (X_{2S})

1.31 metric tons/ha of residual DM (X_{3S})

with a response, at that point, of $\hat{Y}_S = 77.5\%$ of physiologically active grass.

Table 13A. Effect of treatment variables upon the seasonal average percentage of the physiologically active grass component of the mixture on a dry matter basis.

Treat. No.	Variables: Grazing Period	Rest Period	Grazing+ Pressure	Average Physiologically Active Grass
	-------days-------		-metric tons/ha-	-------%--------
1	3.5	14	.788	71.7
2	10.5	14	.892	71.1
3	3.5	42	.897	75.4
4	10.5	42	1.006	83.6
5	3.5	14	1.719	69.1
6	10.5	14	1.714	65.2
7	3.5	42	1.815	73.4
8	10.5	42	1.875	67.7
9	14.0	28	1.448	78.0
10	1.0	28	1.543	76.8
11	7.0	56	1.800	45.4
12	7.0	0	1.213	57.2
13	7.0	28	2.328	76.5
14	7.0	28	.413	82.5
15	7.0	28	1.264	75.7
16	7.0	28	1.410	79.4
17	7.0	28	1.245	80.5
18	7.0	28	1.341	80.3
19	7.0	28	1.548	80.0
20	7.0	42	1.409	75.5
21	7.0	14	1.344	68.0
22	7.0	28	.917	79.0
23	7.0	28	1.775	64.7
24	3.5	28	1.448	78.6

+Residual DM left after grazing.

Table 13B. Analysis of variance of the fitted model for the average physiologically active grass percent of total dry matter.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		.01750	13.543**
Linear		3	.00730	5.615**
Quadratic		6	.02120	16.308**
Residual	14		.00130	
Lack-of-fit		10	.00122	5.083 NS
Error		4	.00024	

** $P < 0.01$

The location of the SP and the response at that point are well within the general region of the experiment and, without considering the other response variables studied, the SP represents very satisfactory operating conditions. It can be seen that 77.5% is well on the upper side of the range observed in the experiment (see Table 13A) and 28 days rest and 1.31 metric tons/ha of residual DM were pre-established as being close to the possible optimum where the compromise between the pasture and animal potential may lie.

In spite of the very satisfactory operating conditions of the SP, as far as physiologically active grass percentage is concerned, it is of interest to examine the response in more detail within the region of the experiment. The canonical form (in arcsine) was

$$\hat{Y} = 1.076 - .00369W_1^2 - .00036W_2^2 + .01745W_3^2,$$

indicating a minimax type of response. The percentage of physiologically active grass may be increased beyond 77.5% only by moving away from the SP along W_3. However, the magnitude of λ_3 (.01745) seems too small for

any significant increase. Movement along W_1 and W_2 away from the SP will, of course, result in smaller percentages of physiologically active grass.

In Fig. 20A, grazing period is fixed at 2 days, and rest period and grazing period are varied. Moving away from the SP along W_3 in both directions within the actual experimental region, very little increment in percentage of physiologically active grass can be accomplished, even though the response tends to increase with somewhat less frequent grazing and heavier grazing pressure which apparently propitiates less litter left after grazing and higher rates of photosynthesis. Another tendency can be observed by moving along W_2 away from the SP, i.e., for the same number of days grazing, the response decreases with longer days of rest and more lenient grazing pressure or with more frequent grazing and somewhat heavier grazing pressure.

In Fig. 20B, the rest period was fixed at 28 days and grazing period and grazing pressure were varied. Significant increases in grass percentage may be achieved by moving along W_3 away from the SP with heavier grazing pressures and somewhat longer grazing periods (up to about 7 days), grazing pressure being the predominant factor (see, for example, treatment no. 14 in Table 13A). Movement along W_1 away from the SP results in a reduced percentage of physiologically active grass, primarily with lighter grazing pressure and longer days of grazing. This condition propitiates accumulation of litter at the lower levels of the pasture canopy, thereby reducing the active photosynthetic area of the grass. Apparently, therefore, litter accumulates with long rest periods, but this may be offset by heavy grazing pressure and, to some extent, by longer grazing periods.

The above discussion can also be visualized by determining points

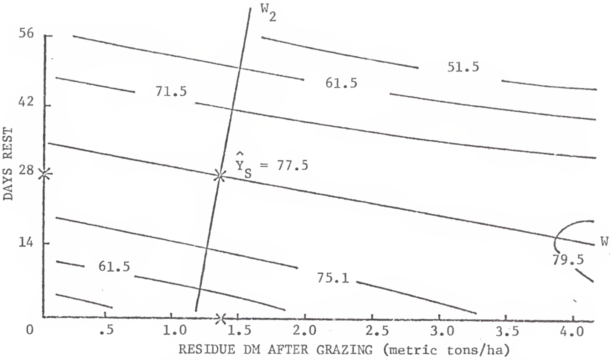


Fig. 20A. Contours of physiologically active grass (%) for 2 days of grazing.

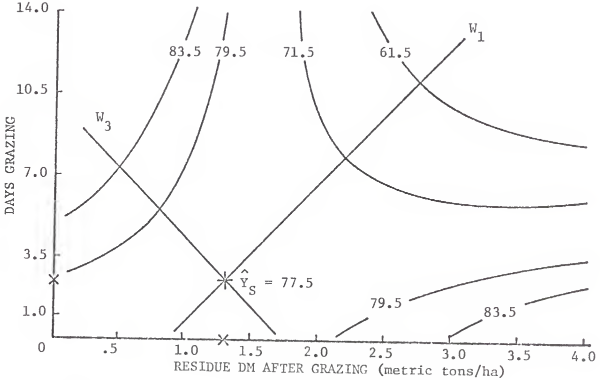


Fig. 20B. Contours of physiologically active grass (%) for 28 days of rest.

along the paths of steepest ascent (along W_3) and descent (along W_1 and W_2). The W's and the X's are associated by the relationship.

$$X_1 = 2.00 + .8806W_1 - .2229W_2 - .41802W_3$$
$$X_2 = 28.00 + .1987W_1 + .9748W_2 - .1013W_3$$
$$X_3 = 1.31 + .4301W_1 + .0061W_2 + .9028W_3$$

Following are some points along the path of steepest ascent, moving along W_3 away from the SP by making W_1 and W_2 equal zero. For example,

W_3	X_1	X_2	X_3	$\hat{Y} = 1.076 + .01745W_3^2$
-1.0	2.5	28.2	.40	79.0
- .5	2.2	28.1	.86	77.8
0	2.0	28.0	1.31	77.5
.5	1.8	27.9	1.76	77.8
1.0	1.5	27.8	2.21	79.0

Points along the path of steepest descent may be found by moving along W_1 and W_2. For example, along W_1

W_1	X_1	X_2	X_3	$\hat{Y} = 1.076 - .00369W_1^2$
-1	1	27.8	.88	77.0
0	2	28.0	1.31	77.5
1	3	28.2	1.74	77.0
2	4	28.5	1.10	76.0

or along W_2

W_2	X_1	X_2	X_3	$\hat{Y} = 1.076 - .00036W_2^2$
-15	5	13	1.22	70.0
-10	4	18	1.25	74.0
- 5	3	23	1.28	77.2
0	2	28	1.31	77.5
5	1	33	1.34	77.2

The relationship (based on the format of canonical form)

$$X_{1S}^{*} = -41.57 + 33.26X_3$$

$$X_{2S}^{*} = 10.64 - 13.42X_3$$

may give predicted grazing days and grazing periods for some fixed values of grazing pressures which may result in maximum percentage of physiologically active grass. These maximums are obtained from $\hat{Y}_S^{*} = b_0^{*} + \frac{1}{2}(X_{1S}^{*}b_1^{*} + X_{2S}^{*}b_2^{*})$. For example, for

$X_3 = 1.31$	$X_{1S}^{*} = 2$	$X_{2S}^{*} = 28.0$	$\hat{Y}_S^{*} = 77.5$
$X_3 = 1.50$	$X_{1S}^{*} = 8$	$X_{2S}^{*} = 30.5$	$\hat{Y}_S^{*} = 77.0$
$X_3 = 2.00$	$X_{1S}^{*} = 24$	$X_{2S}^{*} = 37.5$	$\hat{Y}_S^{*} = 68.5$

The values of $\hat{Y}$, $\hat{Y}_S$, and $\hat{Y}_S^{*}$ were all calculated in terms of arcsine. However, they were ultimately transformed back to percentages and have been presented as such.

Physiologically Active Desmodium Percentage

In spite of a certain lack of uniformity in the establishment of Greenleaf desmodium in the first year and a small general reduction due to factors other than treatment effects, it was possible, during 1975, to evaluate its response due to the experimental variables and some definite trends were noticed from the response surface analysis and, of course, in the field.

Table 14A shows the average desmodium percentage as affected by the treatment variables. Desmodium percentage varied from .1 to 20.4.

Table 14A. Effect of treatment variables upon the seasonal average percentage of physiologically active Greenleaf desmodium component of the mixture on dry matter basis.

Treat. No.	Variables: Grazing Period	Variables: Rest Period	Grazing+ Pressure	Average Physiologically Active Desmodium
	--------days--------		-metric tons/ha-	---------%--------
1	3.5	14	.788	.1
2	10.5	14	.892	.3
3	3.5	42	.897	3.5
4	10.5	42	1.006	4.0
5	3.5	14	1.719	4.0
6	10.5	14	1.714	3.0
7	3.5	42	1.815	7.5
8	10.5	42	1.875	6.4
9	14.0	28	1.448	3.5
10	1.0	28	1.543	3.0
11	7.0	56	1.800	20.4
12	7.0	0	1.213	3.5
13	7.0	28	2.328	4.5
14	7.0	28	.413	.4
15	7.0	28	1.264	2.2
16	7.0	28	1.410	3.0
17	7.0	28	1.245	2.8
18	7.0	28	1.341	2.0
19	7.0	28	1.548	1.7
20	7.0	42	1.409	5.0
21	7.0	14	1.344	1.5
22	7.0	28	.917	.5
23	7.0	28	1.775	7.0
24	3.5	28	1.448	2.0

+Residual DM left after grazing.

The Approximating Model

The percentage of physiologically active desmodium was described by the fitted model (in arcsine)

$$\hat{Y} = -.09292 + .00514X_1 - .00539X_2 + .24787X_3 + .00006X_1^2 + .00021X_2^2 - .01818X_3^2 + .00002X_1X_2 - .00432X_1X_3 - .00208X_2X_3$$

$$r^2 = .91$$

The non-significant lack-of-fit in Table 14B suggests a satisfactory fit of the model to explore the response surface of desmodium percent.

Table 14B. Analysis of variance of the fitted model for average percentage of Greenleaf desmodium of total dry matter.

Source of Variation	d.f.	M.S.	F
Total	23		
Regression	9	.01860	16.550**
Linear	3	.04140	37.636**
Quadratic	6	.00726	6.600**
Residual	14	.00110	
Lack-of-fit	10	.00145	4.462 NS
Error	4	.00032	

* P < 0.01

Analysis of the Fitted Surface

The SP for desmodium percentage was found to be located at

29 days of grazing (X_{1S})

22 days of rest (X_{2S})

2.1 metric tons/ha of residual DM (X_{3S})

and the response at that point was 3.5%. The location of the SP does not represent satisfactory operating conditions because days grazing

fell outside the region of the experimental variables of the experiment. Besides, the response at the SP (3.5% desmodium) is very low and probably of little practical significance. It is then necessary to explore the response within the experimental region.

The canonical equation (in arcsine)

$$\hat{Y} = .186 + .00042X_1^2 + .00016W_2^2 - .01849W_3^2$$

indicates that the response at the SP is a minimax system, increasing by movement away from the SP along W_1 and W_2 and declining with movement along W_3.

In Fig. 21A, fixing grazing period at 29 days (even though outside the experiment), it is very clear that higher percentages of Greenleaf desmodium in the mixture require longer rest periods of the pasture and somewhat lenient grazing (around 1.8 metric tons/ha of residual DM). It may also be increased with more frequent grazing but with very light grazing pressure (more than 2.0 metric tons/ha of residual DM). However, this alternative not only propitiates small increments but also the large amount of residue left may not be of practical significance, for example, as far as animal product per unit area. Fig. 21A also shows that, at that grazing period, the percentage of desmodium declines in the mixture moving along W_3 away from the SP with more frequent grazing and heavier grazing pressure.

Fixing rest period at 22 days (Fig. 21B) and varying grazing period and grazing pressure, it can be seen that, moving along W_3 away from the SP towards the experimental region, the desmodium percentage declines with heavier grazing pressure and fewer days of grazing. Also, at 22 days of grazing, moving along W_1 away from the SP to the right, there is no significant increase in desmodium percentage with lighter grazing

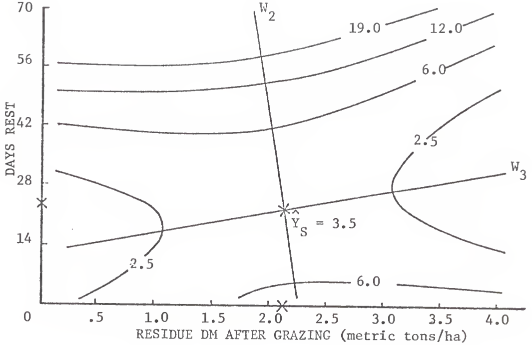


Fig. 21A. Contours of physiologically active desmodium (%) for 29 days of grazing.

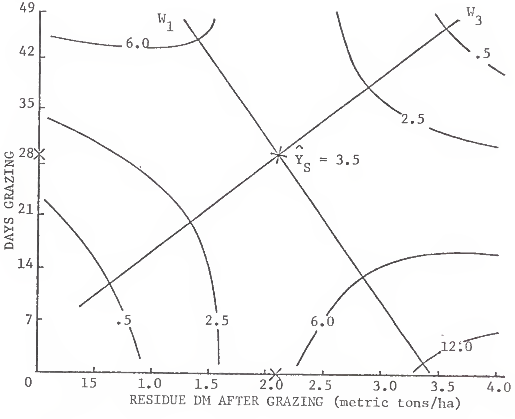


Fig. 21B. Contours of physiologically active desmodium (%) for 22 days of rest.

pressure (up to about 2.5 metric tons/ha of residual DM) because the rest period is in itself not long enough for maintenance of desmodium.

It is apparent from the discussion above that, for satisfactory maintenance of Greenleaf desmodium in the mixture, there must be an association of long rest periods (probably between 42 and 56 days) associated with medium grazing pressures (between 1.5 and 2.0 metric tons/ha of residual DM). Fig. 21C also illustrates this fact. Lenient grazing pressure was particularly important when associated with more frequent grazing. As for grazing period, it appears that, for a given rest period, at the lower permissible levels of residue dry matter for maintenance of desmodium, longer grazing periods may slightly favor the presence of the legume and, at the upper levels of grazing pressure, shorter grazing periods may also favor the legume.

These trends are indicated by movements along the paths of steepest ascent (W_1 and W_2) and descent (W_3). The relationship between the W's and the X's was found to be

$$X_1 = 29.0 + .7528W_1 - .6481W_2 + .1153W_3$$

$$X_2 = 22.0 + .6466W_1 + .7608W_2 + .0552W_3$$

$$X_3 = 2.1 - .1235W_1 + .0330W_2 + .9918W_3$$

Moving along W_1,

W_1	X_1	X_2	X_3	$\hat{Y} = .186 + .000424W_1^2$
-5.0	25	18	2.60	4.0
-2.5	27	20	2.40	3.6
0	29	22	2.10	3.5
2.5	31	24	1.80	3.6
5.0	33	26	1.50	4.0

or along W_2,

Fig. 21C. Effect of rest period and, to some extent, of grazing pressure on Greenleaf desmodium persistence in the pasture.
Left of fence: 7 days grazing, 28 days rest, and 1.4 metric tons of residual DM/ha.
Right of fence: 7 days grazing, 56 days rest, and 1.8 metric tons of residual DM/ha.

W_2	X_1	X_2	X_3	$\hat{Y} = .186 + .000159W_2^2$
-10	35	14	1.76	4.0
- 5	32	18	1.93	3.6
0	29	22	2.10	3.5
5	26	26	2.27	3.6
10	23	30	2.44	4.0

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = .186 - .01850W_3^2$
-1.0	28.8	21.8	1.10	2.8
- .5	28.9	21.9	1.60	3.2
0	29.0	22.0	2.10	3.5
.5	29.1	22.1	2.60	3.2
1.0	29.2	22.2	3.00	2.8

The canonical equation indicates that grazing pressures may be predicted for fixed combination of grazing and rest periods which will give local predicted maximums of desmodium percentage by solving $\frac{d\hat{Y}}{dX_3} = 0$ for X_3 as a function of X_1 and X_2. The following relationship was obtained

$$X_{3S}^{*} = 6.815 - .1187X_1 - .0573X_2$$

The local predicted maximum percentages of desmodium may be obtained from

$$\hat{Y}_S^{*} = b_0^{*} + \frac{1}{2}\,(X_{3S}^{*}b_3^{*})$$

The following combinations of grazing days and rest periods, for example, require respective grazing pressures to obtain a local maximum desmodium percentage. For example, for

$X_1 = 14.0$	$X_2 = 42,$	$X^*_{3S} = 2.7$	$\hat{Y}^*_S = 9.5$
$X_1 = 7.0$	$X_2 = 56,$	$X^*_{3S} = 2.7$	$\hat{Y}^*_S = 19.4$
$X_1 = 10.5$	$X_2 = 56,$	$X^*_{3S} = 2.3$	$\hat{Y}^*_S = 18.5$
$X_1 = 14.0$	$X_2 = 56,$	$X^*_{3S} = 1.9$	$\hat{Y}^*_S = 17.9$
$X_1 = 3.5$	$X_2 = 70,$	$X^*_{3S} = 2.4$	$\hat{Y}^*_S = 40.8$
$X_1 = 7.0$	$X_2 = 70,$	$X^*_{3S} = 1.9$	$\hat{Y}^*_S = 40.6$
$X_1 = 10.5$	$X_2 = 70,$	$X^*_{3S} = 1.6$	$\hat{Y}^*_S = 41.0$
$X_1 = 14.0$	$X_2 = 70,$	$X^*_{3S} = 1.1$	$\hat{Y}^*_S = 41.1$

Again, it is apparent that test period has the predominant effect on the response (see Fig. 21C). Seventy days of rest were included in the above relationship to show the importance of the effect of frequency of grazing on the legume percentage. Apparently, due to the fact that the legume has about half of the photosynthetic rate of that of the grass, it needs much more time to accumulate dry matter as compared to the grass. In addition, it appears that the peak of photosynthetic activity of the grass occurs much faster and then declines, giving opportunity for the legume to contribute more dry matter to the pasture mixture.

The values of $\hat{Y}$, $\hat{Y}_S$, and $\hat{Y}^*_S$ were all calculated in terms of arcsine. However, they were ultimately transformed back to percentages and have been presented as such.

Litter Percentage

In terms of percent dry matter contribution, litter was the second largest component of the total dry matter available. This component was the hand-separated portion of the total biomass made up of dried, decaying, and decayed material not attached to physiologically active

plant material. As seen in Table 15A, the litter component of total dry matter on offer varied from 10.4 to 27.3%. This is the average litter percent for the season in 1975.

The Approximating Model

The approximating model, similar to that for physiologically active grass, was obtained after the actual percentage was transformed to arcsine. The model was

$$\hat{Y} = .58175 - .00562X_1 - .008378X_2 - .00177X_3 - .0007X_1^2 + .00008X_2^2 - .017186X_3^2 - .000186X_1X_2 + .00751X_1X_3 + .00133X_2X_3$$

$$r^2 = .78$$

The analysis of variance for the approximating model is shown in Table 15B and suggests its appropriateness to describe the litter percentage.

Table 15B. Analysis of variance of the fitted model for seasonal average litter percentage of total dry matter.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		.00548	5.535**
Linear		3	.01197	12.091**
Quadratic		6	.00223	2.252+
Residual	14		.00099	
Lack-of-fit		10	.00112	7.466 NS
Error		4	.00015	

** $P < 0.01$

+ $P < 0.075$

Table 15A. Effect of treatment variables upon the seasonal average percentage of the litter component of the mixture on dry matter basis.

Treat. No.	Variables: Grazing Period	Variables: Rest Period	Variables: Grazing[+] Pressure	Average Litter
	-------days-------		-metric tons/ha-	-------%------
1	3.5	14	.788	19.6
2	10.5	14	.892	22.8
3	3.5	42	.897	14.7
4	10.5	42	1.006	10.4
5	3.5	14	1.719	21.7
6	10.5	14	1.714	23.7
7	3.5	42	1.815	12.4
8	10.5	42	1.875	17.7
9	14.0	28	1.448	14.5
10	1.0	28	1.543	20.1
11	7.0	56	1.800	19.0
12	7.0	0	1.213	27.3
13	7.0	28	2.328	18.6
14	7.0	28	.413	11.9
15	7.0	28	1.264	15.8
16	7.0	28	1.410	15.4
17	7.0	28	1.245	15.5
18	7.0	28	1.341	15.8
19	7.0	28	1.548	15.4
20	7.0	42	1.409	16.2
21	7.0	14	1.344	22.5
22	7.0	28	.917	18.6
23	7.0	28	1.775	19.5
24	3.5	28	1.448	17.0

[+]Residual DM left after grazing.

As will be seen later, the quality of the litter is only about half that of, say, physiologically active grass. However, a certain amount of litter is necessary for biological balances at the lower levels of the canopy of the pasture mixture.

Analysis of the Fitted Surface

For litter percentage, the SP was found to be located at

1.5 days of grazing (X_{1S})

38 days of rest (X_{2S})

1.7 metric tons/ha of residual DM (X_{3S})

The average percent litter at that point was $\hat{Y}_S = 16.5$. It can be seen that the SP point is well within the region of the experimental variables and that 16.5% is approximately in the middle of the range observed in the experiment (Table 15A). Therefore, the location of the SP, as far as litter alone is concerned, represents satisfactory operating conditions. Nevertheless, it is necessary to explore the response within the experimental region to verify the effects of the independent variables.

The canonical equation (in arcsine)

$$\hat{Y} = .417 + .00072W_1^2 + .00011W_2^2 - .01799W_3^2$$

indicates a minimax system, the response decreasing by moving away from the SP along W_3 and increasing along W_1 and W_2.

By fixing grazing period at 1.5 days and varying rest period and grazing pressure in Fig. 22A, higher percentages of litter than that at the SP may be obtained by moving along W_2 away from the SP either with longer rest period associated with lighter grazing pressures or with more frequent grazing and slightly heavier grazing. On the other hand, litter percentage declines away from the SP moving along W_3 with heavier

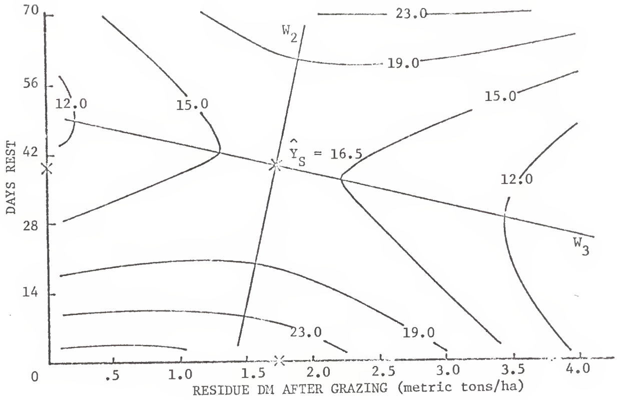


Fig. 22A. Contours of litter (%) for 1.5 days of grazing.

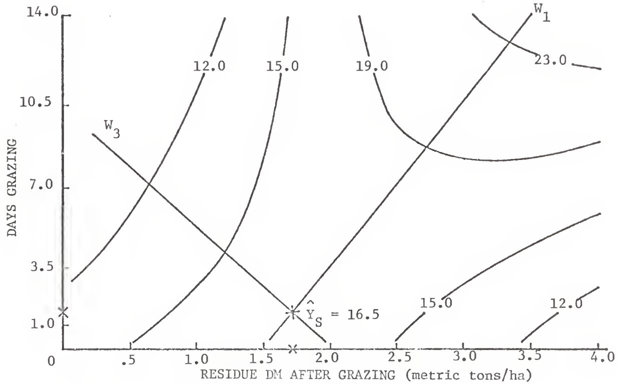


Fig. 22B. Contours of litter (%) for 38 days of rest.

grazing pressures associated with some increase in the length of the rest period, or lighter grazing pressure associated with somewhat shorter rest periods.

In Fig. 22B, the rest period is fixed at 38 days and days grazing and grazing pressure are varied. With this kind of rest period, smaller percentages of litter than 16.5 may be obtained moving along W_3 with heavier grazing pressures and longer grazing periods, or moving along W_1 with lighter grazing pressure and longer grazing periods within the region of the experimental variables.

It can be observed that, in general, since grass was the main component of the mixture and most of the litter came from the grass, grazing management conditions that tended to increase the percentage of physiologically active grass contributed to decreasing litter percentage, especially within the experimental region.

Some points along the paths of steepest ascent (along W_1 and W_2) and descent (along W_3) can also help to interpret the response. The relationship between the canonical variables and the actual experimental variables was found to be

$$X_1 = 1.5 + .9754W_1 - .0804W_2 - .2050W_3$$
$$X_2 = 38.0 + .0743W_1 + .9965W_2 - .0369W_3$$
$$X_3 = 1.7 - .2073W_1 + .0208W_2 + .9780W_3$$

and some points along W_1 may be,

W_1	X_1	X_2	X_3	$\hat{Y} = .417 + .00072W_1^2$
-.5	1.0	37.9	1.80	16.6
0	1.5	38.0	1.70	16.5
.5	2.0	38.1	1.60	16.6
2.5	4.0	38.3	1.20	16.8
5.0	6.5	38.5	.66	17.4

or along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = .417 + .00011W_2^2$
-10	2.5	28	1.50	17.2
- 5	2.0	33	1.60	16.6
0	1.5	38	1.70	16.5
5	1.0	43	1.80	16.6

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = .417 - .01799W_3^2$
-1.0	1.8	38.2	.72	14.4
- .5	1.6	38.1	1.20	15.9
0	1.5	38.0	1.70	16.5
.5	1.4	37.9	2.20	15.9

Depending on whether one would like to predict maximum or minimum values of litter percentage in a pasture for some fixed value of, say, grazing period or grazing pressure or a combination of any two factors, this might be accomplished according to the format of the canonical equation and the location of and the response at the SP. For example, the canonical form indicates that it is possible to predict grazing pressures which give maximum percentages of litter for fixed combinations of grazing period and rest period by solving $\frac{d\hat{Y}}{dX_3} = 0$ for X_3 as a function of X_1 and X_2. The relationship was found to be

$$X_{3S}^* = -.05142 + .21843X_1 + .038637X_2$$

and the predicted maximum litter percentages can be obtained from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}(X_{3S}^* b_3^*)$$

For instance, for

$X_1 = 3.5$	$X_2 = 14,$	$X_{3S}^* = 1.25$	$\hat{Y}_S^* = 21.1$
$X_1 = 3.5$	$X_2 = 28,$	$X_{3S}^* = 1.80$	$\hat{Y}_S^* = 17.4$
$X_1 = 3.5$	$X_2 = 42,$	$X_{3S}^* = 2.33$	$\hat{Y}_S^* = 16.6$
$X_1 = 7.0$	$X_2 = 14,$	$X_{3S}^* = 2.00$	$\hat{Y}_S^* = 22.0$
$X_1 = 7.0$	$X_2 = 28,$	$X_{3S}^* = 2.50$	$\hat{Y}_S^* = 18.6$
$X_1 = 7.0$	$X_2 = 0,$	$X_{3S}^* = 1.48$	$\hat{Y}_S^* = 29.6$

On the other hand, some minimum percentages of litter for fixed amounts of residue left after grazing can also be predicted (see canonical form) by solving $\frac{d\hat{Y}}{dX_1} = 0$ and $\frac{d\hat{Y}}{dX_2} = 0$ for X_1 and X_2 as a function of X_3. The following relationship was obtained,

$$X_{1S}^* = -41.9450 + 25.2989X_3$$
$$X_{1S}^* = 3.4595 + 20.0573X_3$$

and predicted minimum litter percentages could be obtained from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}\,(X_{1S}^* b_1^* + X_{2S}^* b_2^*)$$

For instance, for

$X_3 = 1.7,$	$X_{1S}^* = 1.0$	$X_{2S}^* = 37.5$	$\hat{Y}_S^* = 14.6$
$X_3 = 1.8,$	$X_{1S}^* = 3.5$	$X_{2S}^* = 39.5$	$\hat{Y}_S^* = 15.4$
$X_3 = 2.0,$	$X_{1S}^* = 8.5$	$X_{2S}^* = 43.5$	$\hat{Y}_S^* = 16.0$

The values of $\hat{Y}$, $\hat{Y}_S$, and $\hat{Y}_S^*$ were all calculated in terms of arcsine. They were, however, ultimately transformed back to percentages and have been presented as such.

Physiologically Active Weed Percentage

The weed dry matter contribution in the pasture mixture in 1975 was considerably smaller than in 1974, and the highest concentration occurred early in the season. However, it was still possible to detect the effect of the treatment variables on the weed component in the pasture mixture. Table 16A shows the average percentage of weed on dry matter basis as affected by the different treatments. It varied from 1.1 to 11.8%, the latter in the continuously grazed treatment.

The Approximating Model

The fitted model after the actual percentages were transformed to arcsine was

$$\hat{Y} = .58070 - .01397X_1 - .01027X_2 - .27489X_3 + .00018X_1^2 + .00018X_2^2 + .02689X_3^2 - .00068X_1X_2 + .02139X_1X_3 + .00176X_2X_3$$

$$r^2 = .79$$

Table 16B presents the analysis variance for the fitted model. The satisfactory representation of the response by the model is suggested by the nonsignificant lack-of-fit.

Analysis of the Fitted Surface

For the percentage of weed dry matter contribution, the SP was found to be located at

6.5 days of grazing (X_{1S})

31.5 days of rest (X_{2S})

1.54 metric tons/ha of residual DM (X_{3S})

The location of the SP is well within the domain of the grazing period, rest period and grazing pressure used in the experiment. As a matter of fact, the SP is very close to the pre-established central treatment (7 days of grazing, 28 days of rest, and 1.5 metric tons/ha of residual

Table 16A. Effect of treatment variables upon the season average percentage of physiologically active weed component of the mixture on dry matter basis.

Treat. No.	Variables: Grazing Period	Variables: Rest Period	Variables: Grazing+ Pressure	Average Physiologically Active Weeds
	------days---------		-metric tons/ha-	-------%--------
1	3.5	14	.788	8.6
2	10.5	14	.892	5.8
3	3.5	42	.897	5.3
4	10.5	42	1.006	1.4
5	3.5	14	1.719	3.8
6	10.5	14	1.714	9.8
7	3.5	42	1.815	6.5
8	10.5	42	1.875	4.7
9	14.0	28	1.448	2.5
10	1.0	28	1.543	1.9
11	7.0	56	1.800	6.0
12	7.0	0	1.213	11.8
13	7.0	28	2.328	2.9
14	7.0	28	.413	3.9
15	7.0	28	1.264	3.5
16	7.0	28	1.410	2.2
17	7.0	28	1.245	3.0
18	7.0	28	1.341	2.6
19	7.0	28	1.548	2.8
20	7.0	42	1.409	4.1
21	7.0	14	1.344	7.0
22	7.0	28	.917	1.7
23	7.0	28	1.775	1.1
24	3.5	28	1.448	1.5

+Residual DM left after grazing.

Table 16B. Analysis of variance of the fitted model for average weed percentage of total dry matter.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		.00860	5.770**
Linear		3	.00460	3.087+
Quadratic		6	.01060	7.114**
Residual	14		.00149	
Lack-of-fit		10	.00161	7.594 NS
Error		4	.00021	

** $P < 0.01$

+ $P < 0.075$

DM). The response at the SP was $\hat{Y}_S = 2.5\%$. This response is also very satisfactory since it is on the lower side of the range of weed percentage. Therefore, as far as the weed component alone is concerned, the location of and the response at the SP is very satisfactory. However, these operating conditions may not satisfy other response variables of the pasture complex and it is necessary to look at the response surface within the whole experimental region of the independent variables.

The canonical equation (in arcsine)

$$\hat{Y} = .16 - .00370W_1^2 + .0003W_2^2 + .03070W_3^2$$

indicates that the percentage of weed at the SP is a minimax system. It is a minimum in W_2 and W_3 and a maximum in W_1. Since weeds constitute an undesirable component in the mixture, movement along W_1 away from the SP seems to be the logical way to reduce the weed percentage. Nevertheless, the magnitude (very small) of λ_1 in the canonical equation suggests that very little reduction in weed percentage can be accomplished by moving away from the SP along W_1.

Varying rest period and grazing pressure and fixing grazing period at 6.5 days (Fig. 23A), it can be seen that movement either along W_2 or W_3 will result in higher weed percentage. Within the experimental region, moving along W_3, weed percentage will increase with more frequent grazing associated with heavier grazing pressures or with longer rest periods associated with slightly lighter grazing pressures. Movement along W_2 away from the SP will also result in higher percentages of weed with slightly longer rest periods and heavier grazing pressures, or with somewhat less frequent grazing and more lenient grazing.

By fixing rest period at 31.5 days (Fig. 23B) and varying grazing period and grazing pressure within the experimental region, it is apparent that weed percentage increases with heavier grazing pressures and fewer days of grazing, or with lighter grazing pressures and longer grazing periods. Moving along W_1 with both directions away from the SP indicates that longer grazing periods associated with heavier grazing pressures may reduce weed percentage, or shorter grazing periods associated with lenient grazing pressures. Verification of Table 16A helps to visualize these responses.

The relationships between the independent and dependent variables can probably better be visualized by looking at the association of the W's and the X's and finding points along the paths of steepest ascent and descent. This is true because, over the range considered, grazing period, rest period, and grazing pressure are approximately "compensating", i.e., the independent variables are really changing simultaneously. In other words, if we wish to reduce, say, grazing days, higher (or lower) values of rest period and/or grazing pressure are necessary to compensate the change. This is true, of course, for all response analyses made up to this point. The relationship between the W's and the X's is

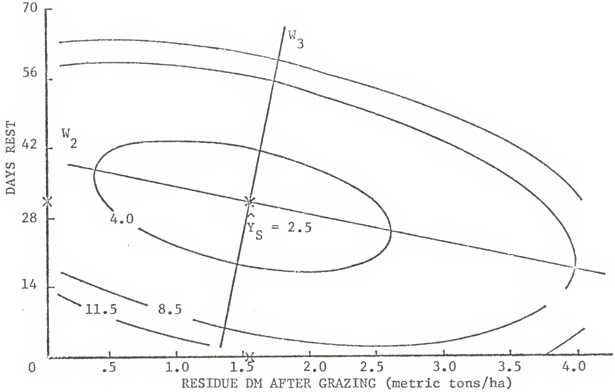


Fig. 23A. Contours of physiologically active weed (%) for 6.5 days grazing.

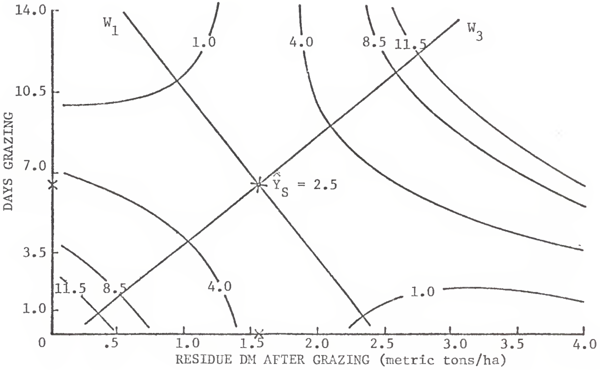


Fig. 23B. Contours of physiologically active weed (%) for 31.5 days of rest.

$$X_1 = 6.50 + .9307W_1 - .1560W_2 + .3308W_3$$
$$X_2 = 31.50 + .1571W_1 + .9873W_2 + .0236W_3$$
$$X_3 = 1.54 + .3303W_1 + .0299W_2 + .9434W_3$$

and movement along W_1 gives points along the path of steepest descent. For example,

W_1	X_1	X_2	X_3	$\hat{Y} = .16 - .0037W_1^2$
-3.0	3.5	31.0	2.53	1.7
-1.5	5.0	31.2	2.00	2.2
0	6.5	31.5	1.54	2.5
1.5	8.0	31.8	1.10	2.2
3.0	9.5	32.0	.55	1.7

and movement along W_2 and W_3 gives points along the path of steepest ascent. For example, along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = .16 + .0003W_2^2$
-15	9.5	16.5	1.10	5.2
-10	8.5	21.5	1.24	3.5
- 5	7.5	26.5	.39	2.9
0	6.5	31.5	1.54	2.5
5	5.5	36.5	1.69	2.9
10	4.5	41.5	1.84	3.5
15	3.5	46.5	2.00	5.2
20	2.5	51.5	2.14	7.6
25	1.5	56.5	2.30	11.6

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = .16 + .0307W_3^2$
-1.0	6.0	31.3	.60	3.6
- .5	6.3	31.4	1.00	2.8
0	6.5	31.5	1.54	2.5
.5	6.7	31.6	2.10	2.8
1.0	7.0	31.7	2.48	3.6

The format of the canonical equation suggests that rest periods and grazing pressures can be predicted for fixed numbers of grazing days which will result in local minimums of weed percentage, since weed is an undesirable component in the mixture. The relationships

$$X_{2S}^* = 3.98 + 4.35X_1$$

$$X_{3S}^* = 4.98 - ..54X_1$$

and

$$\hat{Y}_S^* = b_0^* + \frac{1}{2}(X_{2S}^* b_2^* + X_{3S}^* b_3^*)$$

may give, for example, for

$X_1 = 3.0$,	$X_{2S}^* = 17.0$	$X_{3S}^* = 3.30$	$\hat{Y}_S^* = 1.0$
$X_1 = 5.0$,	$X_{2S}^* = 26.0$	$X_{3S}^* = 2.30$	$\hat{Y}_S^* = 2.1$
$X_1 = 6.5$,	$X_{2S}^* = 31.5$	$X_{3S}^* = 1.54$	$\hat{Y}_S^* = 2.5$
$X_1 = 7.0$,	$X_{2S}^* = 34.5$	$X_{3S}^* = 1.20$	$\hat{Y}_S^* = 2.4$
$X_1 = 8.0$,	$X_{2S}^* = 39.0$	$X_{3S}^* = .66$	$\hat{Y}_S^* = 2.3$

Again, the values of $\hat{Y}$, $\hat{Y}_S$, and $\hat{Y}_S^*$ were calculated in terms of arcsine. However, they were ultimately transformed back to percentages and have been presented as such.

Daily Dry Matter Consumption

The observed average estimated daily dry matter consumption per 100 kg of animal body weight is presented in Table 17A. These observed values were, in general, smaller than the assumed average of 2.5 kg/100 kg BW/day before the experiment was initiated. Dry matter consumption percent varied from about 1.1 to 2.2 kg.

The Approximating Model

Dry matter consumption percent was approximated by the model

$$\hat{Y} = 1.1762 + .1744X_1 - .0274X_2 + .0191X_3 - .0086X_1^2 + .0003X_2^2 - .1373X_3^2 - .0024X_1X_2 + .0383X_1X_3 + .0148X_2X_3$$

$$r^2 = .73$$

Table 17B presents the analysis of variance for the fitted approximating model and the non-significant lack-of-fit suggests that it is satisfactory to represent the response.

Table 17B. Analysis of variance of the fitted model for average daily dry matter consumption per 100 kg of body weight.

Source of Variation	d.f.	M.S.	F
Total	23		
Regression	9	.1688	4.212**
Linear	3	.2536	6.324**
Quadratic	6	.1264	3.152*
Residual	14	.0401	
Lack-of-fit	10	.0493	7.679 NS
Error	4	.0064	

** P < 0.01

* P < 0.05

Table 17A. Effect of treatment variables upon average DM consumption per 100 kg of body weight per day.

Treat. No.	Variables: Grazing Period	Rest Period	Grazing[+] Pressure	DM Consumption per 100 kg BW
	-------days-------		-metric tons/ha-	----kg/day-----
1	3.5	14	.788	1.32
2	10.5	14	.892	2.01
3	3.5	42	.897	1.54
4	10.5	42	1.006	1.20
5	3.5	14	1.719	1.50
6	10.5	14	1.714	1.73
7	3.5	42	1.815	1.35
8	10.5	42	1.875	1.81
9	14.0	28	1.448	1.70
10	1.0	28	1.543	1.11
11	7.0	56	1.800	2.19
12	7.0	0	1.213	2.19
13	7.0	28	2.328	2.00
14	7.0	28	.413	1.17
15	7.0	28	1.264	1.70
16	7.0	28	1.410	1.66
17	7.0	28	1.245	1.70
18	7.0	28	1.341	1.80
19	7.0	28	1.548	1.76
20	7.0	42	1.409	1.44
21	7.0	14	1.344	1.70
22	7.0	28	.917	1.41
23	7.0	28	1.775	1.96
24	3.5	28	1.448	1.62

[+]Residual DM left after grazing.

Analysis of the Fitted Surface

The SP for dry matter consumption was found to be located at

14 days of grazing (X_{1S})

22 days of rest (X_{2S})

3.2 metric tons/ha of residual DM (X_{3S})

and the average consumption at the SP was

$$\hat{Y}_S = 2.15 \text{ kg DM/100 kg BW/day}$$

The average consumption at the SP is very close to the maximum observed in the experiment (see Table 17A). However, the SP is not a satisfactory set of operating conditions since 3.2 metric tons/ha of DM left after grazing was not included in the experiment and, in addition, would probably not be a practical grazing pressure, i.e., it would require an extremely low stocking rate which would result in an extremely undergrazed situation under the conditions of the experiment. Therefore, the response needs to be explored within the actual experimental region of the independent variables.

The canonical equation

$$\hat{Y} = 2.15 - .0059W_1^2 + .0007W_2^2 - .1405W_3^2$$

suggests that the response at the SP is a minimax. It is a maximum in W_1 and W_3 and a minimum in W_2. Movement away from the SP along the canonical axes W_1 and W_3 will result in reduced consumption. Increased consumption will result from movement along W_2.

In Fig. 24A, grazing period was fixed at 14 days and rest period and grazing pressure were varied. Under these conditions, consumption cannot be increased within the domains of the experimental variables since movement along W_2 away from the SP will still require very light grazing pressure. Of course, the very small value of λ_2 supports the above

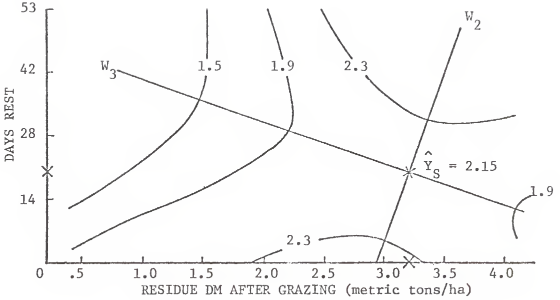


Fig. 24A. Contours of consumption per 100 kg body weight per day (kg) for 14 days of grazing.

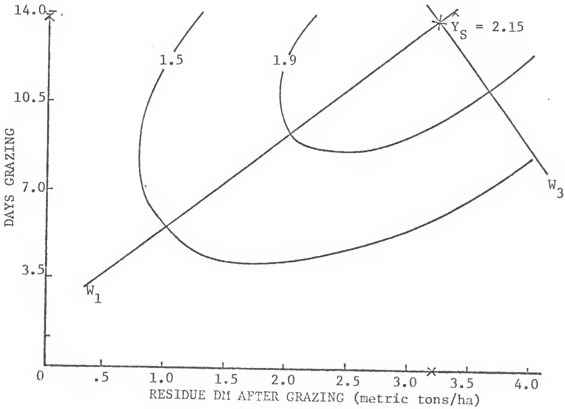


Fig. 24B. Contours of consumption per 100 kg body weight per day (kg) for 22 days of rest.

statement. It is clear, however, that daily consumption percent can be greater than 2.15 kg with more frequent or less frequent grazing as long as grazing pressure stays light. Fig. 24A also indicates (moving along W_3 away from the SP toward the experimental region) that consumption declines with more mature forage (less frequent grazing) and heavier grazing pressures.

In Fig. 24B, rest period was fixed at 22 days. Here again, the predominant effect of grazing pressure on consumption is clear. Moving along W_1 away from the SP towards the region of the independent variables used in the experiment, the average daily dry matter consumption percent declines with increasing grazing pressure. However, this is also associated with shorter grazing periods (see Table 17A).

The trends discussed above may also be seen after some points along the paths of steepest ascent (moving along W_2) and descent (moving along W_1 and W_3) are found. The relationship between the canonical variables and the actual variables is obtained from

$$X_1 = 14.0 + .9893W_1 - .0239W_2 - .1439W_3$$
$$X_2 = 22.0 + .0164W_1 + .9984W_2 - .0532W_3$$
$$X_3 = 3.2 + .1449W_1 + .0503W_2 + .9882W_3$$

and movement along W_2 can give

W_2	X_1	X_2	X_3	$\hat{Y} = 2.15 + .0007W_2^2$
-10	14.5	12	2.50	2.22
- 5	14.2	17	2.90	2.17
0	14.0	22	3.20	2.15
5	13.8	27	3.50	2.17

or along W_1,

W_1	X_1	X_2	X_3	$\hat{Y} = 2.15 - .0059W_1^2$
-12.5	1.5	21.7	1.38	1.23
-10.0	4.0	21.8	1.75	1.56
- 5.0	9.0	21.9	2.48	2.00
0	14.0	22.0	3.20	2.15

or along W_3

W_3	X_1	X_2	X_3	$\hat{Y} = 2.15 - .1405W_3^2$
- 3.0	14.7	22.3	.25	.89
- 2.5	14.6	22.3	.73	1.27
- 2.0	14.5	22.2	1.20	1.58
- 1.0	14.2	22.1	2.20	2.00
0	14.0	22.0	3.20	2.15

The canonical form suggests that for a given fixed rest period, a combination of grazing period and grazing pressure can be obtained from the relationships

$$X_{1S}^{*} = 13.461 + .0245X_2$$

$$X_{3S}^{*} = 1.993 + .0484X_2$$

which will give a local maximum consumption from

$$\hat{Y}_S^{*} = b_0^{*} + \frac{1}{2}\,(X_{1S}^{*}b_1^{*} + X_{3S}^{*}b_3^{*}).$$

So, for example,

$X_2 = 0,$	$X_{1S}^{*} = 14$	$X_{3S}^{*} = 1.99$	$\hat{Y}_S^{*} = 2.37$
$X_2 = 14,$	$X_{1S}^{*} = 14$	$X_{3S}^{*} = 2.60$	$\hat{Y}_S^{*} = 2.18$
$X_2 = 22,$	$X_{1S}^{*} = 14$	$X_{3S}^{*} = 3.20$	$\hat{Y}_S^{*} = 2.15$
$X_2 = 28,$	$X_{1S}^{*} = 14$	$X_{3S}^{*} = 3.30$	$\hat{Y}_S^{*} = 2.20$

It appears that highest consumption may be achieved under continuous

grazing. This can be seen in Table 17A at even lower grazing pressure than X_{3S} = 1.99 as seen above. However, in general, within the experimental region, long grazing periods, associated with short rest periods and light grazing pressures, resulted in the highest dry matter consumption per 100 kg of animal body weight, probably due to the more succulent available forage and the opportunity to selectively graze higher quality forage during a longer period of time. In contrast, using as an example treatments such as no. 4 (10.5 - 42 - 1.006) and no. 10 (1 - 28 - 1.543) and no. 14 (7 - 28 - .413), consumption was very low (see Table 17A). In treatment no. 4, in spite of the somewhat long grazing period, the rest period was long and grazing pressure was heavy; in no. 10, rest period and grazing pressure were medium, but grazing period was minimum; and in no. 14, grazing period and rest period were medium, but grazing pressure was extremely heavy. In all cases, more animals were put in the pasture and invariably forced to graze the pasture to the desired residue. Therefore, all three factors have their effect on dry matter consumption per 100 kg of body weight, grazing pressure having, of course, the greatest influence.

Physiologically Active Grass IVOMD

This response variable was the mean IVOMD of all cycles for each treatment of the total grass on offer sampled immediately before grazing at ground level and not at the expected height corresponding to the desired grazing pressure. The effect of the treatment variables on these seasonal average IVOMD values are presented in Table 18A and varied from 40.2 to 54.9%. The lower side of the range could have been lower still if all the grass litter had been included since, as will be seen in the litter IVOMD analysis, the average litter IVOMD was a little

Table 18A. Effect of treatment variables upon the physiologically active grass IVOMD.

Treat. No.	Variables: Grazing Period	Variables: Rest Period	Grazing+ Pressure	Physiologically Active Grass IVOMD
	-------days-------		-metric tons/ha-	-------%-------
1	3.5	14	.788	54.0
2	10.5	14	.892	50.4
3	3.5	42	.897	49.1
4	10.5	42	1.006	50.6
5	3.5	14	1.719	48.2
6	10.5	14	1.714	46.7
7	3.5	42	1.815	48.1
8	10.5	42	1.875	45.3
9	14.0	28	1.448	50.3
10	1.0	28	1.543	49.2
11	7.0	56	1.800	47.7
12	7.0	0	1.213	45.1
13	7.0	28	2.328	43.5
14	7.0	28	.413	54.9
15	7.0	28	1.264	49.3
16	7.0	28	1.410	50.0
17	7.0	28	1.245	49.8
18	7.0	28	1.341	47.2
19	7.0	28	1.548	47.6
20	7.0	42	1.409	47.3
21	7.0	14	1.344	48.0
22	7.0	28	.917	51.9
23	7.0	28	1.775	48.2
24	3.5	28	1.448	50.0

+Residual DM left after grazing.

less than half of that of the physiologically active grass, and grass litter made up the highest proportion of the total hand-separated litter. The higher side of the range could have been higher if samples had not been taken at ground level. In addition, no sample was taken twice in the same spot in different cycles. Therefore, the residue left after a preceding grazing was always present in the sample.

The Approximating Model

The fitted model for physiologically active grass IVOMD percent was

$$\hat{Y} = 63.6993 - 1.0304X_1 - .0775X_2 - 10.0507X_3 + .0674X_1^2$$
$$- .0022X_2^2 + .9653X_3 + .0107X_1X_2 - .2402X_1X_3 + .1133X_2X_3$$
$$r^2 = .71$$

The analysis of the variance for the model is presented in Table 18B and the non-significant lack-of-fit suggests the adequacy of the model equation to represent the response surface.

Table 18B. Analysis of variance of the approximating model for physiologically active grass IVOMD

Source of Variation	d.f.	M.S.	F
Total	23		
Regression	9	17.8886	4.069**
Linear	3	44.8385	9.703**
Quadratic	6	4.4136	.955 NS
Residual	14	4.6210	
Lack-of-fit	10	5.7755	3.329 NS
Error	4	1.7351	

** $P < 0.01$

Analysis of the Fitted Surface

The SP for grass IVOMD was found to be located at

7 days of grazing (X_{1S})

62 days of rest (X_{2S})

2.45 metric tons/ha of residual DM (X_{3S})

and the IVOMD at that combination of the independent variables was

$$\hat{Y}_S = 45.3\%$$

The location of the SP is not a satisfactory one because 62 days of rest is outside the range of rest periods used in the experiment and, even though 2.45 metric tons/ha of residual DM was within the region of the experiment, such a value was not actually observed in the experiment (see Table 18A). Besides, such a grazing pressure represents an extremely undergrazed situation for the mixture studied and may be of little value in practice. Therefore, it is necessary to explore the response surface in the region of grazing period, rest period and grazing pressure actually used in the experiment.

The transformation of the fitted model to the canonical equation gives

$$\hat{Y} = 45.3 + .05436W_1^2 - .00803W_2^2 + .98420W_3^2$$

indicating that the response at the SP is a minimax system. Movement away from the SP along W_1 and W_3 will result in higher, and along W_2 in lower, total available grass IVOMD percent.

In Fig. 25A, grazing period is fixed at 7 days and rest period and grazing pressure are varied. Moving away from the SP along W_3 towards the experimental region, i.e., to the left, it is very clear that grass IVOMD increases with more frequent grazing and heavier grazing pressures. Fig. 25A also indicates that movement along W_2 away from the SP results

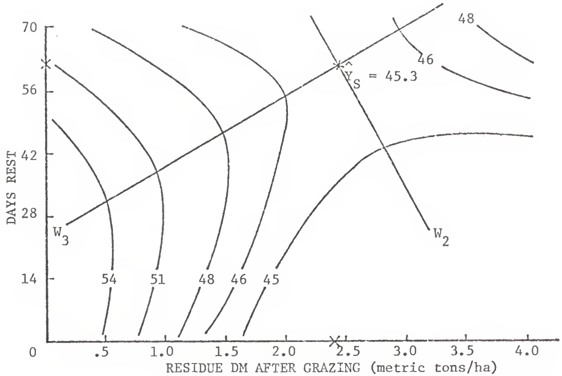


Fig. 25A. Contours of physiologically active grass IVOMD (%) for 7 days of grazing.

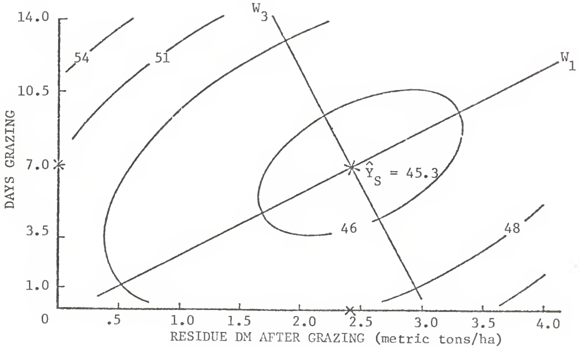


Fig. 25B. Contours of physiologically active grass IVOMD (%) for 62 days of rest.

in lower grass IVOMD percent, but, with grazing days fixed at 7, the graph conveys very little information for the actual experimental region. It does indicate, however, that grass IVOMD is reduced with longer rest period, even with somewhat heavier grazing pressure, which emphasizes the major importance of frequency of grazing on total available grass IVOMD percent. It also emphasizes that, even for somewhat shorter rest periods, lighter grazing pressures also result in reduced total available grass IVOMD because of the accumulated residue left from the previous grazing. These trends can be observed in Table 18A.

In Fig. 25B, the rest period is fixed at 62 days, while days of grazing and grazing pressure are being varied. It would be expected that, at 60 days of rest, changing either grazing pressure or, principally, grazing days, little change would be expected within the region of the experiment. It is clear, however, that (moving along W_1 towards the experimental region) total available grass IVOMD increases with heavier grazing pressure and fewer days of grazing. However, moving along W_3 away from the SP, grass IVOMD will also increase with heavier grazing pressure but with longer grazing periods, suggesting that frequency of grazing and grazing pressure are really the most important factors affecting the response.

The simultaneous changes in the experimental variables, with movements along the canonical variables away from the SP, and the respective changes in grass IVOMD can be obtained from the relationship between the W's and X's,

$$X_1 = 7.00 + .9715W_1 - .1987W_2 - .1294W_3$$

$$X_2 = 62.00 + .2072W_1 + .9767W_2 + .0562W_3$$

$$X_3 = 2.45 + .1152W_1 - .0814W_2 + .9900W_3$$

For example, moving along W_1,

W_1	X_1	X_2	X_3	$\hat{Y} = 45.3 + .05436W_1^2$
-6.0	1.0	61.0	1.75	47.2
-3.5	3.5	61.5	2.00	46.0
0	7.0	62.0	2.45	45.3
3.5	10.5	62.5	2.85	46.0

along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = 45.3 - .00803W_2^2$
- 5	8	57	2.86	45.0
0	7	62	2.45	45.3
5	6	67	2.00	45.0
10	5	72	1.60	44.5
15	4	77	1.23	43.5

and along W_3;

W_3	X_1	X_2	X_3	$\hat{Y} = 45.3 + .9842W_3^2$
-2.0	7.4	61.6	.45	49.2
-1.5	7.3	61.7	.95	47.5
-1.0	7.2	61.8	1.45	46.3
- .5	7.1	61.9	1.95	45.8
0	7.0	62.0	2.45	45.3

Predicted rest periods (due to the format of the canonical equation) can be obtained for combinations of grazing period and grazing pressure which will result in local maximum grass IVOMD for each particular operating condition. The predicted rest period for each combination may be obtained from

$$X_{2S}^{*} = -18.09 + 2.43X_1 + 25.75X_3$$

and the respective local grass IVOMD maximums from

$$\hat{Y}^*_S = b^*_0 + \frac{1}{2}\,(X^*_{2S} b^*_2)$$

Following are some combinations of grazing period (X_1) and grazing pressure (X_3), the predicted rest period (X^*_{2S}) and their respective local grass IVOMD maximum ($\hat{Y}^*_S$).

$X_1 = 1.0$	$X_3 = 1.0$,	$X^*_{2S} = 10.0$	$\hat{Y}^*_S = 53.64$
$X_1 = 3.5$	$X_3 = 1.0$,	$X^*_{2S} = 16.0$	$\hat{Y}^*_S = 51.60$
$X_1 = 7.0$	$X_3 = 1.0$,	$X^*_{2S} = 24.5$	$\hat{Y}^*_S = 50.40$
$X_1 = 10.5$	$X_3 = 1.0$,	$X^*_{2S} = 33.0$	$\hat{Y}^*_S = 51.20$
$X_1 = 14.0$	$X_3 = 1.0$,	$X^*_{2S} = 41.5$	$\hat{Y}^*_S = 53.12$
$X_1 = 1.0$	$X_3 = 1.5$,	$X^*_{2S} = 23.0$	$\hat{Y}^*_S = 50.70$
$X_1 = 3.5$	$X_3 = 1.5$,	$X^*_{2S} = 29.0$	$\hat{Y}^*_S = 48.60$
$X_1 = 7.0$	$X_3 = 1.5$,	$X^*_{2S} = 37.5$	$\hat{Y}^*_S = 47.60$
$X_1 = 10.5$	$X_3 = 1.5$,	$X^*_{2S} = 46.0$	$\hat{Y}^*_S = 48.30$
$X_1 = 14.0$	$X_3 = 1.5$,	$X^*_{2S} = 55.0$	$\hat{Y}^*_S = 51.20$
$X_1 = 1.0$	$X_3 = 2.0$,	$X^*_{2S} = 36.0$	$\hat{Y}^*_S = 48.80$
$X_1 = 3.5$	$X_3 = 2.0$,	$X^*_{2S} = 42.0$	$\hat{Y}^*_S = 46.90$
$X_1 = 7.0$	$X_3 = 2.0$,	$X^*_{2S} = 50.5$	$\hat{Y}^*_S = 45.84$
$X_1 = 10.5$	$X_3 = 2.0$,	$X^*_{2S} = 59.0$	$\hat{Y}^*_S = 46.70$

Physiologically Active Grass Crude Protein

Like grass IVOMD, grass crude protein (CP) percent was the season average of all cycles for each treatment of the total grass on offer sampled immediately before each grazing period at ground level. It varied from 7.9 to 18.1%, a considerably wide range (Table 19A).

The Approximating Model

The fitted approximating model for grass CP percent was

$$\hat{Y} = 28.6171 - .3806X_1 - .1445X_2 - 12.6136X_3 + .0175X_1^2 - .0042X_2^2 + .3638X_3^2 - .0005X_1X_2 + .0366X_1X_3 + .2454X_2X_3$$

$$r^2 = .77$$

The lack-of-fit in the analysis of variance of the fitted equation in Table 17B is not significant, indicating that the response surface can be satisfactorily approximated by the model.

Table 19B. Analysis of variance of the fitted model for total available grass CP content.

Source of Variation	d.f.		M.S.	F
Total	23			
Regression	9		13.6172	5.302**
Linear		3	32.0212	13.258**
Quadratic		6	4.4152	1.719 NS
Residual	14		2.5685	
Lack-of-fit		10	2.9150	1.713 NS
Error		4	1.7020	

** $P < 0.01$

Table 19A. Effect of treatment variables upon the physiologically active grass crude protein (CP).++

Treat. No.	Variables: Grazing Period	Rest Period	Grazing+ Pressure	Physiologically Active Grass CP
	-------days-------		-metric tons/ha-	-------%-------
1	3.5	14	.788	18.1
2	10.5	14	.892	16.5
3	3.5	42	.897	11.7
4	10.5	42	1.006	10.5
5	3.5	14	1.719	11.0
6	10.5	14	1.714	10.6
7	3.5	42	1.815	8.8
8	10.5	42	1.875	8.5
9	14.0	28	1.448	12.6
10	1.0	28	1.543	13.5
11	7.0	56	1.800	11.5
12	7.0	0	1.213	10.7
13	7.0	28	2.328	7.9
14	7.0	28	.413	17.5
15	7.0	28	1.264	13.6
16	7.0	28	1.410	13.1
17	7.0	28	1.245	12.6
18	7.0	28	1.341	12.4
19	7.0	28	1.548	10.2
20	7.0	42	1.409	10.0
21	7.0	14	1.344	12.2
22	7.0	28	.917	14.9
23	7.0	28	1.775	13.8
24	3.5	28	1.448	12.6

+Residual DM left after grazing.

++On an organic matter basis.

Analysis of the Fitted Surface

The analysis of the fitted surface indicates that the SP for grass CP percent was found to be located at

9 days of grazing (X_{1S})

44 days of test (X_{2S})

2.1 metric tons/ha of residual DM (X_{3S})

For that combination of experimental variables, the grass CP content was

$$\hat{Y}_S = 10.3\%$$

Even though the SP is located within the domains of the experimental variables used in the experiment, 10.3% CP is more toward the lower side of the observed range (Table 19A). This is, of course, primarily due to the relatively long rest period (44 days) associated with the relatively high residual dry matter left after grazing (2.1 metric tons/ha). Therefore, the SP does not represent very satisfactory operating conditions and the response surface should be further explored within the experimental region.

The canonical equation

$$\hat{Y} = 10.3 + .01721W_1^2 - .04192W_2^2 + .40175W_3^2$$

suggests a minimax response system. As would be expected, the nature of this response surface is similar to that of grass IVOMD since CP content is fairly closely correlated positively with IVOMD. The canonical equation indicates that a higher grass CP content than 10.3% may be secured with movements away from the SP along W_1 and W_3. Movement along W_2 will result in lower grass CP content.

Fixing grazing period at 9 days and varying frequency of grazing and grazing pressure (Fig. 26A), it can be clearly seen (as with grass IVOMD) that moving away from the SP toward the experimental region along W_3, grass

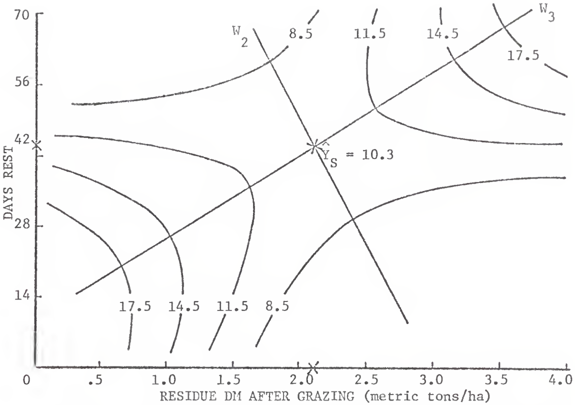


Fig. 26A. Contours of physiologically active grass crude protein (%) for 9 days of grazing.

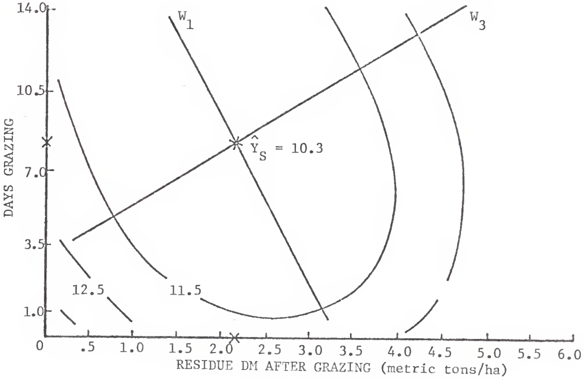


Fig. 26B. Contours of physiologically active grass crude protein (%) for 44 days of rest.

CP percent increases with shorter rest periods associated with heavier grazing pressures. Movement along W_3 to the right of the SP is of no interest since it leads to conditions outside the region of the experimental variables and probably of no biological meaning. Fig. 26A also shows that, still within the experimental region, movement along W_2 away from the SP will result in small reductions in grass CP content with longer rest period even with slightly heavier grazing pressure, or with somewhat shorter rest periods and slightly lighter grazing pressures. Therefore, for these conditions of grazing period, the importance of frequency of grazing and grazing pressure on the grass CP content is evident.

When days of rest is fixed at 42 days and days of grazing and grazing pressure are varied (Fig. 26B), moving along W_3 away from the SP toward the experimental region of interest (to the left), the grass CP content increases with heavier grazing pressures (less residual dry matter left after grazing) and somewhat shorter grazing periods. Of course, the increments cannot be very substantial for a given increase in grazing pressure because the rest period (44 days) is a long period in itself which again indicates the predominant effect of rest period on forage quality. Movement along W_1 away from the SP in both directions will also result in increments in grass CP. However, within the region of interest, little can be achieved with heavier grazing pressure and longer grazing periods. This indicates, as with grass IVOMD, that rest period (primarily) and grazing pressure are the most important grazing management factors affecting the quality of the total available grass for grazing.

Simultaneous changes in grazing period, rest period and grazing pressure with movement along the W variables and the corresponding predicted grass CP percent may be obtained from

$$X_1 = 9.0 + .9945W_1 + .0939W_2 + .0453W_3$$

$$X_2 = 44.0 - .1031W_1 + .9518W_2 + .2889W_3$$

$$X_3 = 2.1 - .0160W_1 - .2920W_2 + .9563W_3$$

Points may be obtained with movement along W_1, for example,

W_1	X_1	X_2	X_3	$\hat{Y} = 10.3 + .01720W_1^2$
-8.0	1.0	44.8	2.23	11.4
-5.0	4.0	44.5	2.20	10.7
-2.5	6.5	44.3	1.16	10.5
0	9.0	44.0	2.10	10.3
2.5	11.5	43.7	2.06	10.5
5.0	14.0	43.5	2.00	10.7

or along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = 10.3 - .04192W_2^2$
-2	8.8	42	2.68	10.1
0	9.0	44	2.10	10.3
2	9.2	46	1.52	10.1
4	9.4	48	.93	9.6
6	9.6	50	.35	8.8

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = 10.3 + .4017W_3^2$
-1.5	8.7	43.4	.66	11.2
-1.0	8.8	43.6	1.14	10.7
- .5	8.9	43.8	1.62	10.5
0	9.0	44.0	2.10	10.3
.5	9.1	44.1	2.57	10.5

The format of the canonical equation indicates (as in the case of grass IVOMD) that rest periods may be obtained for fixed combinations of

grazing period and grazing pressure which will result in predicted maximum grass CP percentages for the given combination. The relationship between X^*_{2S} and X_1 and X_3 is given by

$$X^*_{2S} = -16.814 - .0595X_1 + 29.214X_3$$

and the predicted maximum grass CP percentage for particular combination of X_1, X_3 and X^*_{2S} is calculated from

$$\hat{Y}^*_S = b^*_0 + \frac{1}{2}(X^*_{2S}b^*_2)$$

Some of those predicted maximums are given below:

$X_1 = 1.0$	$X_3 = 1.0$,	$X^*_{2S} = 12.5$	$\hat{Y}^*_S = 16.05$
$X_1 = 3.5$	$X_3 = 1.0$,	$X^*_{2S} = 12.2$	$\hat{Y}^*_S = 15.98$
$X_1 = 7.0$	$X_3 = 1.0$,	$X^*_{2S} = 12.0$	$\hat{Y}^*_S = 15.40$
$X_1 = 10.5$	$X_3 = 1.0$,	$X^*_{2S} = 11.8$	$\hat{Y}^*_S = 15.24$
$X_1 = 14.0$	$X_3 = 1.0$,	$X^*_{2S} = 11.6$	$\hat{Y}^*_S = 15.52$
$X_1 = 1.0$	$X_3 = 1.5$,	$X^*_{2S} = 27.0$	$\hat{Y}^*_S = 13.22$
$X_1 = 3.5$	$X_3 = 1.5$,	$X^*_{2S} = 26.8$	$\hat{Y}^*_S = 12.55$
$X_1 = 7.0$	$X_3 = 1.5$,	$X^*_{2S} = 26.6$	$\hat{Y}^*_S = 12.00$
$X_1 = 10.5$	$X_3 = 1.5$,	$X^*_{2S} = 26.4$	$\hat{Y}^*_S = 11.90$
$X_1 = 14.0$	$X_3 = 1.5$,	$X^*_{2S} = 26.2$	$\hat{Y}^*_S = 11.77$

$X_1 = 1.0$	$X_3 = 2.0,$	$X_{2S}^* = 41.6$	$\hat{Y}_S^* = 11.65$
$X_1 = 3.5$	$X_3 = 2.0,$	$X_{2S}^* = 41.4$	$\hat{Y}_S^* = 11.10$
$X_1 = 7.0$	$X_3 = 2.0,$	$X_{2S}^* = 41.2$	$\hat{Y}_S^* = 10.60$
$X_1 = 10.5$	$X_3 = 2.0,$	$X_{2S}^* = 41.0$	$\hat{Y}_S^* = 10.50$
$X_1 = 14.0$	$X_3 = 2.0,$	$X_{2S}^* = 39.8$	$\hat{Y}_S^* = 10.70$
$X_1 = 1.0$	$X_3 = 2.5,$	$X_{2S}^* = 56.0$	$\hat{Y}_S^* = 12.20$
$X_1 = 3.5$	$X_3 = 2.5,$	$X_{2S}^* = 55.8$	$\hat{Y}_S^* = 11.59$
$X_1 = 7.0$	$X_3 = 2.5,$	$X_{2S}^* = 55.6$	$\hat{Y}_S^* = 11.13$
$X_1 = 10.5$	$X_3 = 2.5,$	$X_{2S}^* = 55.4$	$\hat{Y}_S^* = 11.10$
$X_1 = 14.0$	$X_3 = 2.5,$	$X_{2S}^* = 55.2$	$\hat{Y}_S^* = 11.50$

It can be noticed again that, for practically the same combination of rest period and grazing pressure, variation in the number of grazing days has little or no effect on the response. Rest period and grazing pressure are the main factors affecting the response. It is interesting to note that, when X_{2S}^* is 56 days or very close to 56 days, even though the pasture is undergrazed, the CP percent of the total grass on offer is not much different from that when the rest period is around 42 days and even at a lower grazing pressure. This difference is apparently due to the fact that the treatment with 56 days rest had the highest contribution of Greenleaf desmodium and it appears that the grass benefited from the nitrogen fixed by the legume (see treatment no. 11 in Table 14A and 19A).

Litter IVOMD

Since litter was an important component of the total forage dry matter on offer (see Table 15A), representative composite samples of most treatment combinations obtained toward the end of the season were analyzed for IVOMD and the results are presented in Table 20A. The litter IVOMD varied from 16.26 to 21.7%, i.e., less than half those values for the physiologically active grass IVOMD.

The Approximating Model

The approximating model for litter IVOMD was

$$\hat{Y} = 17.3158 + .1083X_1 + .0862X_2 + 4.3281X_3 - .0103X_1^2 - .0010X_2^2$$
$$- 2.1849X_3^2 - .0007X_1X_2 - .0009X_1X_3 - .0283X_2X_3$$
$$r^2 = .68$$

Table 20B contains the analysis of variance to test the adequacy of the model. The non-significant lack-of-fit suggests its appropriateness to describe the response.

Table 20B. Analysis of variance of the fitted model for litter IVOMD.

Source of Variation	d.f.		M.S.	F
Total	20			
Regression	9		4.4136	2.828^{+}
Linear		3	7.6931	4.929*
Quadratic		6	3.8261	2.451^{++}
Residual	11		1.5609	
Lack-of-fit		7	1.6120	1.010 NS
Error		4	1.5968	

* $P < 0.05$

$^{+}$ $P < 0.075$

$^{++}$ $P < 0.10$

Table 20A. Effect of treatment variables upon litter IVOMD.

	Variables			
Treat. No.	Grazing Period	Rest Period	Grazing+ Pressure	Litter IVOMD++
	------days--------		-metric tons/ha-	---%----
1	3.5	14	.788	21.1
2	10.5	14	.892	20.5
3	3.5	42	.897	20.8
4	10.5	42	1.006	20.5
5	3.5	14	1.719	–
6	10.5	14	1.714	–
7	3.5	42	1.815	18.5
8	10.5	42	1.875	–
9	14.0	28	1.448	18.4
10	1.0	28	1.543	18.9
11	7.0	56	1.800	16.1
12	7.0	0	1.213	20.0
13	7.0	28	2.328	16.3
14	7.0	28	.413	19.1
15	7.0	28	1.264	21.6
16	7.0	28	1.410	21.7
17	7.0	28	1.245	19.4
18	7.0	28	1.341	18.2
19	7.0	28	1.548	20.9
20	7.0	42	1.409	19.5
21	7.0	14	1.344	18.2
22	7.0	28	.917	20.3
23	7.0	28	1.775	16.3
24	3.5	28	1.448	19.1

+Residual DM left after grazing.

Analysis of the Fitted Surface

The analysis of the fitted surface indicates that the SP was found to be at

4 days of grazing (X_{1S})

31 days of rest (X_{2S})

.8 metric tons/ha of residual DM (X_{3S})

and the litter IVOMD at that point was 20.6%. First, it can be noticed that the SP is well within the region of the experimental variables used in the experiment. Second, 20.6% IVOMD is very close to the observed maximum (Table 20A).

The canonical equation

$$\hat{Y} = 20.6 - .01034W_1^2 - .00087W_2^2 - 2.1850W_3^2$$

indicates that the litter IVOMD at the SP is a global maximum. Movement along any of the canonical axes will result in lower litter IVOMD.

If we were looking for the predicted maximum litter IVOMD under the conditions of the experiment, 4 days of grazing, 31 days of rest, and .8 metric tons/ha of residual DM left after grazing would be the ideal treatment combination. However, those conditions may not be as adequate for other response variables of the complex of the pasture mixture. Therefore, it is of interest to look at the response within the whole experimental region.

Fig. 27A has the grazing period fixed at 4 days, while rest period and grazing pressure are varied. Under those conditions, it can be seen that, within the region of interest, moving along W_3 away from the SP, the litter IVOMD decreases with less frequent grazing associated with lighter grazing pressures. Movement along W_2 within the experimental region, in both directions, also results in reduced litter IVOMD. How-

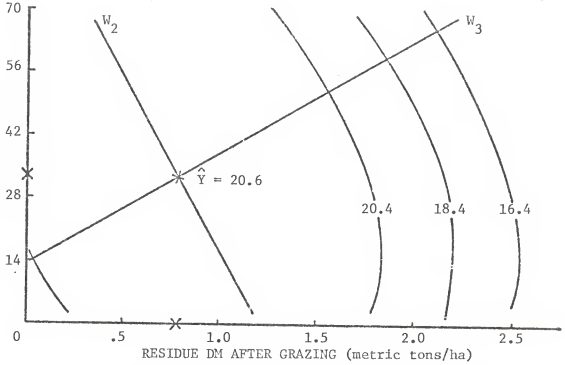


Fig. 27A. Contours of litter IVOMD (%) for 4 days of grazing.

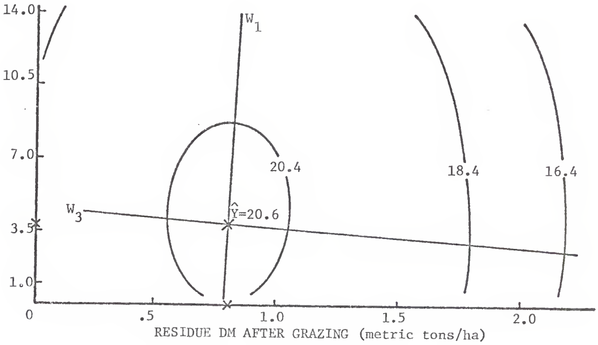


Fig. 27B. Contours of litter IVOMD (%) for 31 days of rest.

ever, little change is noticed (see λ_2 in canonical form) because, in one direction, heavier grazing pressure is offset by less frequent grazing and, in the other direction, more frequent grazing is offset by lighter grazing pressure. It is obvious that heavy grazing pressure will result in animals consuming most of the accumulated litter and, if there is a short rest period, there will be less accumulation of litter and the quality of the litter will probably be better. Table 20A suggests these trends and the predominant effect of grazing pressure.

In Fig. 27B, rest period is fixed at 31 days while grazing period and grazing pressure are being varied. Moving along W_1 results in practically no change in litter IVOMD since grazing pressure is practically the same for all lengths of grazing period, i.e., W_1 is an almost vertical line in relation to the grazing pressure axis. Movement along W_3 away from the SP in the region of most interest (to the right) indicates that litter IVOMD is again reduced with lighter grazing pressures with little change in the length of grazing period, i.e., for a given combination of grazing period and rest period, litter IVOMD declines with lenient grazing pressures.

The relationship between the canonical and the actual variables is given by

$$X_1 = 4.0 + .9992W_1 - .0386W_2 + .0002W_3$$
$$X_2 = 31.0 + .0386W_1 + .9992W_2 + .0065W_3$$
$$X_3 = .8 - .0005W_1 - .0065W_2 + .9999W_3$$

and movement along the canonical axes will support the above discussions. For example, along W_1,

W_1	X_1	X_2	X_3	$\hat{Y} = 20.6 - 01034W_1^2$
− 3	1	30.8	.82	20.51
− 2	2	30.9	.81	20.55
0	4	31.0	.80	20.60
2	6	31.1	.79	20.55
4	8	31.3	.78	20.43
8	12	31.5	.77	19.94
10	14	31.6	.76	19.57

or along W_2,

W_2	X_1	X_2	X_3	$\hat{Y} = 20.6 - .00087W_2^2$
−17	4.6	14	.91	20.35
−15	4.5	16	.89	20.40
−10	4.4	21	.86	20.50
− 5	4.2	26	.83	20.57
0	4.0	31	.80	20.60
5	3.8	36	.77	20.57
10	3.6	41	.74	20.50
15	3.4	46	.71	20.40
20	3.2	51	.68	20.25
25	3.0	56	.65	20.00

or along W_3,

W_3	X_1	X_2	X_3	$\hat{Y} = 20.6 - 2.1850W_3^2$
- .4	3.8	30.8	.40	20.25
- .2	3.9	30.9	.60	20.51
0	4.0	31.0	.80	20.60
.2	4.1	31.1	1.00	20.51
.4	4.2	31.2	1.20	20.25
.6	4.3	31.3	1.40	19.80
.8	4.4	31.4	1.60	19.20
1.0	4.5	31.5	1.80	18.40
1.2	4.6	31.6	2.00	17.45

Again, movements along W_1, W_2 and W_3 away from the SP indicates that grazing pressure is the most important factor affecting litter IVOMD, followed by rest period and very little or no effect from grazing period.

Since grazing pressure is the predominant factor affecting litter IVOMD, it might be of interest to predict grazing pressures for fixed grazing management systems which would give maximum litter IVOMD. From the discussion above and the format of the canonical equation, it is obvious that, for combinations of different grazing periods with the same rest period, the grazing pressure should be approximately the same and the predicted maximums should be very close to but below the maximum obtained at the SP. The relationship between X_{3S}^* and X_1 and X_2 was

$$X_{3S}^* = .9905 - .000215X_1 - .006486X_2$$

and the maximums ($\hat{Y}_S^*$'s), obtained from

$$\hat{Y}_S^* = b_0^* + \frac{1}{2} (X_{3S}b_3^*).$$

For,

$X_1 = 1.0$	$X_2 = 14,$	$X^*_{3S} = .90$	$\hat{Y}^*_S = 20.18$
$X_1 = 3.5$	$X_2 = 14,$	$X^*_{3S} = .90$	$\hat{Y}^*_S = 20.30$
$X_1 = 7.0$	$X_2 = 14,$	$X^*_{3S} = .90$	$\hat{Y}^*_S = 20.27$
$X_1 = 10.5$	$X_2 = 14,$	$X^*_{3S} = .90$	$\hat{Y}^*_S = 19.98$
$X_1 = 14.0$	$X_2 = 14,$	$X^*_{3S} = .89$	$\hat{Y}^*_S = 19.42$
$X_1 = 1.0$	$X_2 = 28,$	$X^*_{3S} = .81$	$\hat{Y}^*_S = 20.45$
$X_1 = 3.5$	$X_2 = 28,$	$X^*_{3S} = .81$	$\hat{Y}^*_S = 20.57$
$X_1 = 7.0$	$X_2 = 28,$	$X^*_{3S} = .81$	$\hat{Y}^*_S = 20.50$
$X_1 = 10.5$	$X_2 = 28,$	$X^*_{3S} = .81$	$\hat{Y}^*_S = 20.16$
$X_1 = 14.0$	$X_2 = 28,$	$X^*_{3S} = .80$	$\hat{Y}^*_S = 19.57$
$X_1 = 1.0$	$X_2 = 42,$	$X^*_{3S} = .72$	$\hat{Y}^*_S = 20.41$
$X_1 = 3.5$	$X_2 = 42,$	$X^*_{3S} = .72$	$\hat{Y}^*_S = 20.48$
$X_1 = 7.0$	$X_2 = 42,$	$X^*_{3S} = .72$	$\hat{Y}^*_S = 20.37$
$X_1 = 10.5$	$X_2 = 42,$	$X^*_{3S} = .72$	$\hat{Y}^*_S = 20.00$
$X_1 = 14.0$	$X_2 = 42,$	$X^*_{3S} = .71$	$\hat{Y}^*_S = 19.38$
$X_1 = 1.0$	$X_2 = 56,$	$X^*_{3S} = .63$	$\hat{Y}^*_S = 20.00$
$X_1 = 3.5$	$X_2 = 56,$	$X^*_{3S} = .63$	$\hat{Y}^*_S = 20.03$
$X_1 = 7.0$	$X_2 = 56,$	$X^*_{3S} = .62$	$\hat{Y}^*_S = 19.90$
$X_1 = 10.5$	$X_2 = 56,$	$X^*_{3S} = .62$	$\hat{Y}^*_S = 19.50$
$X_1 = 14.0$	$X_2 = 56,$	$X^*_{3S} = .62$	$\hat{Y}^*_S = 19.28$

Animal Performance

Pasture quality in terms of animal performance could only be evaluated in the replicated central treatment (7 days grazing, 28 days rest, and 1.5 metric tons/ha of residual DM) and in the continuously grazed treatment (with 1.5 metric tons/ha of residual DM).

Table 21 shows the seasonal average daily gain/animal for the two treatments with their respective observed grazing pressures. The seasonal

Table 21. Effect of treatment variables upon daily liveweight gain per animal--season average.

Variables			
Grazing Period	Rest Period	Grazing Pressure+	LW gain/head/day
--------days--------		--metric tons/ha--	--------kg-------
7	28	1.360	.46
7	0	1.213	.35

+ Residual DM left after grazing.

average daily gain per animal was higher (.46 kg) for the central treatment than for the continuously grazed pasture (.35 kg). Animal performance for the central treatment may be considered reliable, since three tester animals were maintained in the treatment throughout the experiment. However, in the continuously grazed treatment, performance was based on only one tester and, therefore, was not a reliable figure.

Animal performance at the central point--which for the experiment was thought to be close to the optimum compromise between pasture and animal potentials--was not very satisfactory, since .46 kg of gain/animal/day actually represents a somewhat low seasonal average daily

gain for improved pastures. There was no loss of animal body weight during the experimental period. The average daily gains per animal were .70, .47, .37, .58, and .29 kg, respectively for the first, second, third, fourth, and fifth cycles of the central treatment. As far as animal performance is concerned, a shorter rest period (possibly around 21 days) and a somewhat lighter grazing pressure (possibly between 1.5 and 1.8 metric tons/ha of residual DM) would probably be a better compromise between animal and pasture potentials for the pasture studied. Rest period and grazing pressure at the central treatment were not compatible with maintenance of Greenleaf desmodium in the pasture and the legume could be an important factor influencing animal performance. Therefore, the optimum might also include longer rest periods (possibly 42 days) and lighter grazing pressure (possibly between 1.5 and 2.0 metric tons/ha of residual DM). In the first case, the grass would probably be the main pasture component and, in the second, a satisfactory grass-desmodium mixture might be obtained. Animal performance would probably increase under both conditions. Of course, other factors, principally animal product per unit area, should be considered.

SUMMARY AND CONCLUSIONS

A grass-legume mixture composed primarily of Coastcross-1 bermudagrass (Cynodon dactylon (L.), Pers.) and Greenleaf desmodium (Desmodium intortum (Mill) Urb.) was evaluated in a grazing trial during 182 days in the growing season of 1975 at the Beef Research Unit, University of Florida, Gainesville. The grass-legume mixture was established in 1974 on a soil of the Sparr series associated with the Blanton series.

The grazing trial had as its main objectives (a) to determine the response of the mixture to various treatment combinations of the grazing management factors, i.e., grazing period, rest period and grazing pressure; (b) to evaluate a response surface design in agronomic experiments for forage evaluation under grazing; (c) to determine the feasibility of using the forage residue left after grazing as an estimator of grazing pressure; (d) to generate coefficients from the response surface for forage-livestock feeding programs; and (e) to provide information for further forage and pasture research.

Each grazing management factor was studied at five levels, namely, grazing period: 1, 3.5, 7, 10.5, and 14 days; rest period: 0, 14, 28, 42, and 56 days; and grazing pressure: .5, 1.0, 1.5, 2.0, and 2.5 metric tons/ha of dry matter (DM) left after grazing.

A modified non-rotatable Central Composite Response Surface Design was used and 20 treatment combinations were used to cover the five planes of the 5^3 complete factorial. The 20 treatments were composed of eight factorial, six axial, one central, and five extra treatments, the latter five to cover the ranges of grazing period, rest period, and

grazing pressure. The central treatment (7 days grazing, 28 days rest and 1.5 metric tons of residue DM) was replicated five times in order to obtain an estimate of the experimental error of the experiment.

The 24 experimental pastures were accomodated in an area of 2.7 ha, and 37 put-and-take Brown Swiss-Angus heifers were used to defoliate the pastures to the desired projected amount of residue dry matter.

The response variables studied included: total forage on offer per cycle, forage growth rate, net forage dry matter yield, dry matter on offer per hundred kilos body weight, litter percentage, physiologically active grass, Greenleaf desmodium and weed percent on a dry matter basis, grass in vitro organic matter digestibility (IVOMD), grass crude protein percent (CP%), litter IVOMD, and dry matter consumption.

For both dry matter yields and botanical composition, a double-sampling procedure was used. For each cycle, sampling was made before and after grazing. Twenty random $0.5m^2$ plots were randomly selected in each pasture and the height of the forage on offer (or residue) was measured with a forage meter and visually estimated for total yield and yield contribution of each component of the mixture. Ten of those plots were randomly selected and harvested at ground level for actual determination of yield and botanical composition which was then used for correction of the indirect estimates through regression. In this dissertation, for the correction through double-sampling, the forage meter height was used as the independent and dry matter as the dependent variable. Therefore, all 20 observations were ultimately used in the estimate of the response variables used in the response surface analysis. The "paired" cage technique was used for sampling in the continuously grazed pasture and in the treatment with 14 days of grazing.

The statistical analysis of the response variables involved (1) ap-

proximating the response with a second-order model of the type $\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$ where X_1 = grazing period, X_2 = rest period, and X_3 = residual dry matter; (2) testing the model; (3) finding the stationary point (SP), the response at that point, and the canonical equation; (4) describing the response at the SP within the experimental region of the independent variables and, (5) when feasible, making interpolations to obtain predicted local maximum responses for fixed values of one or two independent variables.

From the results obtained in this experiment, some general conclusions may be emphasized:

1. Visually estimated residual dry matter left after grazing can be a very satisfactory estimator of grazing pressure in grazing experiments and can be applied in practice. An individual can, with practice and periodic double sampling, make very satisfactory predictions of the amount of residue dry matter left after grazing. However, this method will often require the put-and-take technique.

2. The Central Composite Design was very useful, not only because it allowed for the reduction in the number of treatment combinations which would otherwise be used in the complete factorial to study the whole response surface, but also because it allowed for modifications in the formal design, even though it became non-rotatable. It also allowed for extra treatment combinations of interest to be added to the basic non-rotatable design.

3. The concepts of Stationary Point and Canonical Analysis, illustrated with appropriate contours of equal response, proved to be very useful approaches in the analysis of the response surface, not only because they aid in predicting optimum grazing management conditions

for individual and/or multiple response variables within the general region of the independent variables, but also because they helped to interpret the relationships between the experimental variables (grazing period, rest period and grazing pressure) and the response variables. This should generally be true when two or more experimental factors are involved and each factor is studied at three or more levels. It can also help to predict maximum (or minimum) responses and aid in determining combinations of the independent variables and expected responses for further experimentation.

4. For all response variables studied, the second-degree approximating model seemed to be satisfactory, even though, at times, the non-significance of lack-of-fit was borderline at 1% level of significance. In a few cases this was due to the unusually low observed experimental error, leaving a large portion of the sums of squares for lack-of-fit. In this respect, it seems appropriate to replicate other strategic treatments besides the central point based on predicted variances of the predicted response of different points according to the design to be used. Replications of the central treatment may or may not provide the true experimental error of the experiment, and, consequently, the fitted model may or may not be the appropriate model to represent the response. This is important because if the model is adequate in the experimental region, the analysis of the fitted surface will certainly approximate the analysis of the physical systems.

5. In this experiment, where multiple responses were analyzed, it was difficult to establish an overall optimum operating condition of days grazing, days rest, and grazing pressure because the different response variables in the pasture-animal system react differently to the different combinations of grazing management factors. However,

depending on the interest of the researcher, the analysis can predict maximums, minimums, and optimum responses for individual as well as for two or more response variables.

6. Even though the purpose of the analysis of response surface is not really to determine which of the factors under study has the most effect on a given response but, instead, which combinations of the factors give optimum (or maximum or minimum) responses, it may also explain the underlying mechanism of the system. From the analysis, it can be inferred, within the region of the experimental variables used in the experiment, that grazing pressure and rest period had predominant influences on the nature of all of the responses. In most cases, however, grazing period had a complementary effect. In general, within the experimental region:

a) Total DM available per cycle increased with longer rest period (less frequent grazing), lighter grazing pressures and increasing days of grazing.

b) Average forage growth rate and, consequently, total net forage yield was higher with medium grazing pressure and medium rest period associated with long grazing periods.

c) Stocking rate in terms of animals per hectare per day and liveweight per hectare per day was primarily a function of grazing pressure. It increased primarily with heavier grazing pressure associated with shorter rest periods, with little effect of grazing period.

d) Daily dry matter on offer per 100 kg of body weight was primarily a function of grazing pressure. It increased with lighter grazing pressure (more residual DM left after grazing) associated with increasing lengths of rest period, with very little influence of grazing period.

e) Physiologically active grass percent was higher with heavier grazing pressures and medium rest periods associated with medium to long grazing periods.

f) Physiologically active desmodium percent was mainly a function of rest period. It increased with long rest periods associated with medium to lighter grazing pressures. However, shorter rest periods with lighter grazing pressures may maintain some legumes in the mixture. This response apparently is independent of grazing period.

g) Litter percent increased with increasing lenghts of rest period and lighter grazing pressures. These were the unfavorable conditions for physiologically active grass percentage.

h) Daily dry matter consumption increased with frequent grazing associated with light grazing pressures and long grazing periods.

i) IVOMD of total grass on offer was higher with more frequent grazing and heavier grazing pressure. At mid rest periods, grazing pressure has a major effect on grass IVOMD. Similar responses were found for CP percent of grass on offer, however, it appeared that, at 56 days rest, increased percentage of Greenleaf desmodium increased the grass CP.

j) Litter IVOMD was higher with short rest periods and heavier grazing pressures.

k) The animal performance indicates that a good compromise between the pasture and animal potentials apparently requires grazing management systems other than that of the central treatment with the average observed residual DM. In this respect further research is required.

7. In general, the experiment indicated which treatment combinations should be eliminated or maintained for further experimentation depending on the response variable being studied and which direction to take, i.e., which combination of the independent variables will more efficiently increase or decrease the response.

8. Confirmatory experiments may be advisable before results are ultimately released for practical application.

REFERENCES

Auda, H., R. E. Blaser and R. H. Brown. 1966. Tillering and carbohydrate contents of orchardgrass as influenced by environmental factors. Crop Sci. 6:139-143.

Baker, B. S., and G. A. Jung. 1968. Effect of environmental conditions on the growth on four perennial grasses. I. Response to controlled temperature. Agron. J. 60:155-158.

Balaam, L. N. 1975. Response surface designs. In: V. J. Bofinger and J. L. Wheeler (ed.) Developments in field experiment design and analysis. Commonwealth Agricultural Bureaux, Oxford.

Barr, A. J. and J. H. Goodnight. 1971. Statistical analysis system. North Carolina University Press, Raleigh.

Bisset, W. J., and G. W. C. Marlowe. 1974. Productivity and dynamics of two Siratro based pastures in the Burnett coastal foothills of southeast Queensland. Trop. Grassl. 8:17-24.

Blaser, R. E. 1966. Effecto del animal sobre la pastura. In: O. Paladines (ed) Empleo de los animales en las investigaciones sobre pasturas. IICA-Zona Sur.

___________, H. T. Bryant, C. Y. Ward, R. C. Hammes, Jr., R. C. Carter and N. H. McLeod. 1959. Symposium on Forage Evaluation: IV. Animal performance and yields with methods of utilizing pasturage. Agron. J. 51:238-242.

___________, R. C. Hammes, Jr., H. T. Bryant, C. M. Kincaid, W. H. Skrdla, T. H. Taylor and W. L. Griffeth. 1956. The value of forage species and mixtures for fattening steers. Agron. J. 48:508-513.

___________, J. R. Harlan and R. M. Love. 1962. Grazing management. In: Pasture and range research techniques. p. 11-17. Comstock Publishing Associates, Ithaca.

___________, E. Jahn and R. C. Hammes, Jr. 1974. Evaluation of forage and animal research. In: Systems analysis in forage crops production and utilization. Crop Sci. Soc. Am. Spec. Pub. No. 6.

___________, D. D. Wolf and H. T. Bryant. 1973. Systems of grazing management. In: M. E. Heath, D. S. Metcalfe and R. E. Barnes (ed.) Forages. The Iowa State University Press, Ames.

Box, G. E. P. 1954. The exploration and exploitation of response surfaces: Some general considerations and examples. Biometrics 10: 16-60.

Box, G. E. P., and J. S. Hunter. 1954. Multi-factor experimental designs. N. C. State C. of Ag. and Engr., Inst. Statist. Off. Ord. Res. Contract, Tech. Rep. No. 6.

___________, and J. S. Hunter. 1957. Multi-factor experimental designs for exploring response surfaces. Ann. Math. Statist. 28:195-241.

___________, and K. B. Wilson. 1951. On the experimental attainment of optimum conditions. J. Roy. Statist. Soc., B, 13:1-45.

Bredon, R. M., and C. R. Horrell. 1961. The chemical composition and nutritive value of some common grasses in Uganda. I. Trop. Agric. 38:297-304.

Brenes, L. R., F. J. Marchán and J. I. Cabrera. 1949. The utilization of grasses, legumes and other forage crops for cattle feeding in Puerto Rico. 2. Comparison of fertilized Guinea grass, Para grass, and tropical Kudzu alone as pasture crops. J. Agric. Univ. Puerto Rico. 33:85-97.

Brougham, R. W. 1956. Effect of intensity of defoliation on regrowth of pasture. Austr. J. Agric. Res. 7:377-387.

Brown, R. H., and R. E. Blaser. 1970. Soil moisture and temperature effects on growth and soluble carbohydrates of orchardgrass (Dactylis glomerata). Crop Sci. 10:213-216.

Bryan, W. W. 1968. Grazing trials on the Wallum of southeastern Queensland. I. A comparison of four pastures. Austr. J. Exp. Agric. Anim. Husb. 8:512-520.

__________. 1970. Changes in botanical composition in some tropical sown pastures. Int. Grassl. Congr., Proc. 11th, 636-639.

__________, and T. R. Evans. 1973. Effects of soils, fertilizers and stocking rate on pastures and beef production on the Wallum of southeastern Queensland. I. Botanical composition and chemical effects on plants and soils. Austr. J. Exp. Agric. Anim. Husb. 13:516-529.

__________, J. P. Sharp and K. P. Haydock. 1971. Some factors affecting the growth of lotononis (Lotononis bainesii). Austr. J. Exp. Agric. Anim. Husb. 11:29-34.

Buller, R. E., S. Aronovich, L. R. Quinn and W. V. A. Bisschoff. 1970. Performance of tropical legumes in the upland savannah of central Brazil. Int. Grassl. Congr., Proc. 11th, 143-146.

Butterworth, M. H. 1961. Studies on pangolagrass at I.C.T.A., Trinidad. II. The digestibility of pangolagrass at various stages of growth. Trop. Agric. 38:189-193.

Chamblee, D. S. 1962. Small-plot experiments. In: Pasture and range research techniques. p. 147-164. Comstock Publishing Associates, Ithaca.

Cochran, W. G., and G. M. Cox. 1957. Experimental designs. John Wiley & Sons, Inc., New York.

Cohen, R. D. H., and A. D. O'Brian. 1974. Beef production from three pastures at Grafton, N. S. W. Trop. Grassl. 8:71-79.

Conway, A. 1965. Grazing management in relation to beef production. Int. Grassl. Congr., Proc. 9th, 1601-1607.

Coward-Lord, J., J. A. Arroyo-Aguilú and O. García-Molinari. 1974. Proximate nutrient composition of 10 tropical grasses. J. Agric. Univ. Puerto Rico 58:305-311.

Cowlishaw, S. J. 1969. The carrying capacity of pastures. J. Brit. Grassl. Soc. 24:207-214.

Cruz, V., and S. S. Benachio. 1965. Comparative grazing of criollo steers grazing pangola and guineagrass and criollo heifers grazing pangola, guineagrass and stargrass. Int. Grassl. Congr., Proc. 9th, 1671-1674.

Dawson, J. E. 1975. Block-grazing in Westland on the Kokatahia Beef Unit. N. Z. J. Agric. 130:19-21.

Delgado, A., and F. Alfonso. 1974. Effect of grazing systems and stocking rate on beef fattening in tropical areas. Int. Grassl. Congr., Proc. 12th, 152-161.

Dillon, J. L. 1966. Economic considerations in the design and analysis of agricultural experiments. Rev. Mktg. Agric. Econ., Sydney. 34:64-75.

Edwards, P. J. 1974. Estimates of carrying capacity and production from herbage yields and grazing days. Proc. Grassl. Soc. South Africa 9:139-143.

Evans, T. R. 1970. Some factors affecting beef production from subtropical pastures in the coastal lowlands of southeast Queensland. Int. Grassl. Congr., Proc. 11th, 803-807.

Falvey, L. 1975. Effect of mowing frequency and height on Townsville stylo (Stylosanthes humilis) pastures on cleared Blain soil. Trop. Agric. 52:143-147.

Gartner, J. A., J. E. Ferguson, R. W. Walker and E. A. Joward. 1974. Evaluating perennial grass/legume swards on the Atherton tableland in north Queensland. Qsd. J. Agric. Anim. Sci. 31:1-17.

Gilmore, L. and A. J. Rose. 1970. APL/360: An interactive approach. John Wiley & Sons, Inc., New York.

Goonewardene, L. A., and R. R. Appadurai. 1972. Animal production potential of three important fodder grasses of Sri Lanka. I. Liveweight gains with sheep. Trop. Agriculturist 128:25-34.

Groff, B., W. A. T. Harding and R. F. Woolcock. 1970. Effects of cutting on three ecotypes of Stylosanthes guyanensis. Int. Grassl. Congr., Proc. 11th, 226-230.

Haggar, R. J., and M. B. Ahmed. 1970. Seasonal production of Andropogon gayanus. II. Seasonal changes in digestibility and feed intake. J. Agric. Sci. 75:369-373.

Hamilton, R. I., L. J. Lambourne, R. Roe and D. J. Minson. 1970. Quality of tropical grass for milk production. Int. Grassl. Congr., Proc. 11th, 860-864.

Hancock, J. 1958. The conversion of pasture to milk. The effect of stocking rate and concentrate feeding. J. Agric. Sci. 50:284-295.

Harland, J. R. 1958. Generalized curves for gain per head and gain per acre in rates of grazing studies. J. Range Manage. 11:140-147.

Herriot, J. B. D., and D. A. Wells. 1963. The grazing animal and the sward productivity. J. Agric. Sci. 61:89-99.

Hodgson, J. 1976. The effect of the grazing animal on herbage quality and utilization. Herb. Abstr. 46(3):92.

Homb, T. 1953. Chemical composition and digestibility of grassland crops. Acta. Agric. Scand. 3:1-32.

Humphreys, L. R. 1966. Pasture defoliation practice: A review. J. Austr. Inst. Agric. Sci. 32:93-105.

Imrie, B. C. 1971. The effects of severity of defoliation and soil moisture stress on Desmodium intortum. Austr. J. Exp. Agric. Anim. Husb. 11:521-524.

Ivins, J. B., J. Dilnot and J. Davison. 1958. The interpretation of data of grassland evaluation in relation to the varying potential outputs of grassland and livestock. J. Brit. Grassl. Soc. 13:23-28.

Jeffrey, H., and J. M. Holder. 1971. The nutritive value of some pasture species examined in a subtropical environment. Trop. Grassl. 5:117-130.

Johnson, W. L., and D. Pezo. 1975. Cell-wall fractions and in vitro digestibility of Peruvian feedstuffs. J. Anim. Sci. 41:185-197.

Jones, R. J. 1967. Effect of close cutting and nitrogen fertilizer on the growth of a Siratro (Phaseolus atropurpureus) pasture at Samford, southeastern Queensland. Austr. J. Exp. Agric. Anim. Husb. 7:157-161.

__________. 1973. The effect of frequency and severity of cutting on yield and persistance of Desmodium intortum cv Greenleaf in a subtropical environment. Austr. J. Exp. Agric. Anim. Husb. 13:171-177.

Jones, R. J. 1974a. Effect of an associate grass, cutting interval, and cutting height on yield and botanical composition of Siratro pastures in a subtropical environment. Austr. J. Exp. Agric. Anim. Husb. 14:334-342.

__________. 1974b. Stocking rate effects on three different pastures. CSIRO Div. Trop. Agron. Ann. Rep. 1973-74, p. 17.

__________. 1975. Population dynamics of Siratro. CSIRO Div. Trop. Agron. Ann. Rep. 1974-75, p. 7.

__________, and R. L. Sandland. 1974. The relationship between animal gain and stocking rate. J. Agric. Sci. 83:335-342.

Kennedy, W. R., J. T. Reid and M. J. Anderson. 1959. Evaluation of animal production under different systems of grazing. J. Dairy Sci. 42:679-685.

Keya, N. C. O. 1974a. Grass/legume pastures in Western Kenya. I. A comparison of the productivity of cut and grazed swards. E. Afr. Agric. For. J. 39:240-246.

____________. 1974b. Grass/legume pasture in Western Kenya. II. Legume performance at Kitale, Kisu, and Kakamega. E. Afr. Agric. For. J. 39:247-257.

Kien, L. T. 1975. Fertilizer effects on 'Pangola' and 'Transvala' digitgrass and 'Coastcross 1' bermudagrass. M. S. Thesis, Univ. Florida.

Koger, M., W. G. Blue, G. B. Killinger, R. E. L. Greene, H. C. Harris, J. M. Myers, A. C. Warnick and N. Gammon, Jr. 1961. Beef production, soil and forage analysis, and economic returns from eight pasture programs in north central Florida. Univ. Florida IFAS Agric. Exp. Sta. Bul. No. 631.

Kretschmer, A. E., G. H. Snyder, J. B. Brolmann and J. G. Gascho. 1974. Seasonal distribution of dry matter and crude protein in tropical grass-legume mixtures in south Florida. Int. Grassl. Congr., Proc. 12th, 309-314.

Littell, R. C., and G. O. Mott. 1974. Computer assisted design and analysis of response surface experiments in Agronomy. Proc. Soil and Crop Sci. Soc. Florida 34:94-97.

Lowe, K. F. 1974. Sod seeding Siratro into native pastures--2 years after. Trop. Grassl. 8:125-128.

Lucas, H. L. 1974. Design and analysis of feeding experiments with milking dairy cows. Inst. Statist. Mimeo Ser. No. 8. N. C. State Univ., Raleigh.

Lucas, I. A. M., and C. P. McMeekan. 1959. The effect of stocking upon a comparison of break and rotational paddock grazing for dairy cows. N. Z. J. Agric. Res. 2:707-718.

Mannetje, L. T. 1974. Relations between pasture attribute and live-weight gains on a subtropical pasture. Int. Grassl. Congr., Proc. 12th, 386-390.

Maraschin, G. E. 1975. Response of a complex tropical pasture mixture to different grazing management systems. Ph.D. Dissertation. Univ. Florida.

______________, and G. O. Mott. 1975. Response of tropical legumes to grazing management systems. In: 5a. Reunión latino americana de producción animal (Maracay, Venezuela).

Matches, A. G. 1970. Pasture research methods. Proc. Nat. Conf. Forage Quality, Evaluation and Utilization (Lincoln, Neb.).

May, L. H. 1960. The utilization of carbohydrate reserves in pasture plants after defoliation. Herb. Abstr. 30(A):239-245.

McFeely, P. C., and D. Browne. 1974. The effect of grazing interval on liveweight gain and carcass weight. Int. Grassl. Congr., Proc. 12th, 398-407.

McLeod, L. B. 1965. Effect of nitrogen and potassium fertilization on the yield, regrowth and carbohydrate content of the storage organs of alfalfa and grasses. Agron. J. 57:345-350.

McMeekan, C. P. 1956. Grazing management and animal production. Int. Grassl. Congr., Proc. 7th, 146-156.

______________, and M. J. Walshe. 1963. The inter-relationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. J. Agric. Sci. 61:147-163.

Mellor, W., M. J. Hibberd and B. Grof. 1973. Beef cattle liveweight gains from mixed pastures of some guinea grasses and legumes on the wet tropical coast of Queensland. Qsd. J. Agric. Anim. Sci. 30: 259-266.

Mendenhall, W. 1968. Introduction to linear models and the design and analysis of experiments. Wadsworth Publishing Co., Inc., Belmont.

Milford, R. 1960. Nutritional values for 17 tropical grasses. Austr. J. Agric. Res. 11:138-148.

__________, and K. P. Haydock. 1965. The nutritive value of protein in subtropical pasture species grown in southeast Queensland. Austr. J. Exp. Agric. Anim. Husb. 5:13-17.

__________, and D. J. Minson. 1966. Intake of tropical pasture species. Int. Grassl. Congr., Proc. 9th, 815-822.

Minson, D. J. 1971. The nutritive value of tropical pastures. J. Austr. Inst. Agric. Sci. 37:255-263.

Minson, D. J., C. E. Harris, W. F. Raymond and R. Milford. 1964. The digestibility and voluntary intake of SS and H-1 ryegrass, S170 tall fescue, S48 timothy, S215 meadow fescue and germinal cocksfoot. J. Brit. Grassl. Soc. 19:298-305.

__________, and M. N. McLeod. 1970. The digestibility of temperate and tropical grasses. Int. Grassl. Congr., Proc. 11th, 719-722.

__________, and R. Milford. 1967. The voluntary intake and digestibility of diets containing different proportions of legume and mature Pangolagrass (Digitaria decumbens). Austr. J. Exp. Agric. Anim. Husb. 7:546-551.

Moore, A. W. 1965. The influence of fertilization and cutting on a tropical grass-legume pasture. Exp. Agric. 1:193-198.

Moore, J. E., G. L. Ellis, C. E. Rios and M. Koger. 1969. Estimates of voluntary intake and nutrient digestibility of bahiagrass pastures by grazing steers. Proc. Soil and Crop Sci. Soc. Florida 29:168-175.

__________, and G. O. Mott. 1973. Structural inhibitors of quality in tropical grasses. In: Symposium on antiquality components in forages. Spec. Pub. No. 3. The American Society of Agronomy, Madison.

__________, G. O. Mott, D. G. Dunham and R. W. Omer. 1972. Large capacity in vitro organic matter digestion procedure. J. Anim. Sci. 35:232 (Abstr.).

Morley, F. H. W., and C. R. W. Spedding. 1968. Agricultural systems and grazing experiments. Herb. Abstr. 38:279-287.

Mott, G. O. 1960. Grazing pressure and the measurement of pasture production. Int. Grassl. Congr., Proc. 8th, 606-611.

__________. 1966. Interpretación correcta de resultados con animales en experimentos de pastoreo. In: O. Paladines (ed.) Empleo de los animales en las investigaciones sobre pasturas. ICA-Zona Sur.

__________. 1973. Evaluating forage production. In: M. E. Heath, D. S. Metcalfe and R. E. Barnes (ed.) Forages. The Iowa State University Press, Ames.

__________. 1974. Nutrient recycling in pastures. In: D. A. Mays (ed.) Forage fertilization. The American Society of Agronomy, Madison.

__________, and H. L. Lucas. 1952. The design, conduct and interpretation of grazing trials on cultivated and improved pastures. Int. Grassl. Congr., Proc. 6th, 1380-1385.

__________, and J. E. Moore. 1970. Forage evaluation in perspective. Proc. Nat. Conf. Forage Quality, Evaluation and Utilization (Lincoln, Neb.).

Mott, G. O., and H. L. Popenoe. 1975. Ecophysiology of tropical grasslands. In: Ecophysiology of tropical crops, CEPLAC, Itabuna (Brazil). p. 44.

Myers, L. F. 1972. Effects of grazing and grazing systems. In: J. H. Leigh and J. C. Noble (ed.) Plants for sheep in Australia. Angus and Robertson, Sydney.

__________, J. V. Lovett and M. H. Walker. 1974. Screening of pasture plants: A proposal for standardizing procedures. J. Austr. Inst. Agric. Sci. 40:283-289.

Myers, R. H. 1971. Response surface methodology. Allyn and Bacon, Inc., Boston.

Norman, M. J. T., and L. J. Phillips. 1970. Wet season grazing of Townsville stylo pasture at Katherine. Austr. J. Exp. Agric. Anim. Husb. 10:710-715.

Olsen, F. J. 1973. Effects of cutting management on a Desmodium intortum (Mill.) Urb./Setaria sphacellata (Schumach.) mixture. Agron. J. 65:714-716.

Partridge, I. J., and E. Ranacow. 1974. The effect of supplemental Leucaena leucocephala browse on steers grazing Dichanthium caricosum in Fiji. Trop. Grassl. 8:107-112.

Petersen, R. G., H. R. Lucas and G. O. Mott. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron. J. 57:27-30.

Phillips, D. S. M., and S. E. Clarke. 1971. The calibration of a weighted disc against pasture dry matter yield. Proc. N. Z. Grassl. Assn. 33:66-75.

Powell, T. L. 1974. Evaluation of weighted disc meter for pasture yield estimation on intensively stocked dairy pasture. N. Z. J. Exp. Agric. 2:237-241.

Reid, J. T., W. K. Kennedy, K. L. Turk, S. T. Slack. G. W. Trimberger and R. P. Murphy. 1959. Effect of growth stage, chemical composition, and physical properties upon the nutritive value of forages. J. Dairy Sci. 42:567-571.

Riewe, M. E. 1961. Use of the relationship of stocking rate to gain of cattle in an experimental design for grazing trials. Agron. J. 53:309-313.

__________. 1966. An experimental design for grazing trials using the relationship of stocking rate to animal gain. Int. Grassl. Congr., Proc. 9th, 1507-1510.

__________, and H. Lippke. 1970. Considerations in determining the digestibility of harvested forages. Proc. Nat. Conf. Forage Quality, Evaluation and Utilization (Lincoln, Neb.).

Roberts, C. R. 1974. Some problems of establishment and management of legume-based tropical pastures. Trop. Grassl. 8:61-67.

Robinson, P. 1960. Composite designs in agriculture research. Can. Dep. Agric., Statist. Res. Serv. Res. Brch., Processed Pub. No. 6.

Rojas, B. 1962. The "San Cristobal" design for fertilizer experiments. Proc. Int. Soc. Sugar Cane Tech. (Mauritius) 11:147-203.

________. 1971. The orthgononalized "San Cristobal" design. Proc. Int. Soc. Sugar Cane Tech. (Louisiana) 14:1-9.

Shiftlet, N. T., and H. F. Heady. 1971. Specialized grazing systems: Their place in range management. U. S. D. A., S. C. S.-TP-152. 13 p.

Siewerdt, L. 1974. Growth behaviour and nutritive value of Phaseolus atropurpureus D. C. cv 'Siratro' swards and other tropical pasture legumes. Herb. Abstr. 46(2):56.

Smith, D. 1973. Physiological considerations in forage management. In: M. E. Heath, D. S. Metcalfe and R. E. Barnes (ed.) Forages. The Iowa State University Press, Ames.

Smith, K. L. 1974. Forage sampling techniques and evaluation of factors affecting steer gains on Midland Bermudagrass. Dissertation Abstracts International 34:4790.

Smith, R. C. G., and W. A. Williams. 1974. Deferred grazing of mediterranean annual pasture: A study by computer simulation. Int. Grassl. Congr., Proc. 12th, 646-655.

Snedecor, G. W., and W. G. Cochran. 1973. Statistical methods. The Iowa State University Press, Ames.

Spedding, C. R. W. 1954. Pasture management to control worms in sheep. Agriculture, London, 61:51-54.

Sprague, V. C. 1944. The effect of temperature and day length on seedling emergence and early growth of several pasture species. Proc. Soil Sci. Am. 8:278-294.

Steel, R. G. D., and J. M. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York.

Stobbs, T. H. 1969a. The effect of grazing management upon pasture productivity in Uganda. I. Stocking rate. Trop. Agric. 46:187-194.

__________. 1969b. The effect of grazing management upon pasture productivity in Uganda. II. Grazing frequency. Trop. Agric. 46:195-200.

__________. 1969c. The effect of grazing management upon pasture productivity in Uganda. III. Rotational and continuous grazing. Trop. Agric. 46:293-301.

Stobbs, T. H. 1969d. The effect of grazing management upon pasture productivity in Uganda. IV. Selective grazing. Trop. Agric. 46:303-309.

__________. 1971. Production and composition of milk from cows grazing Siratro (Phaseolus atropurpureus) and Greenleaf desmodium (Desmodium intortum). Austr. J. Exp. Agric. Anim. Husb. 11:268-273.

__________. 1973. The effect of plant structure on the intake of tropical pastures. II. Differences in sward structure, nutritive value, and bite sizes of animals grazing Setaria anceps and Chloris guyana at various stages of growth. Austr. J. Agric. Res. 24:821-829.

__________. 1975. The effect of plant structure on the intake of tropical pasture. III. Influence of fertilizer nitrogen on the size of bite harvested by Jersey cows grazing Setaria anceps cv Kaxungula swards. Austr. J. Agric. Res. 26:997-1007.

Sullivan, J. T. 1966. Studies of the hemicellulose of forage plants. J. Anim. Sci. 25:83-86.

Till, A. R., and P. E. May. 1970. Nutrient cycling in grazed pastures. II. Further observations with [^{35}S] gypsum. Austr. J. Agric. Sci. 21:253-260.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Brit. Grassl. Soc. 18:104-111.

Tothill, J. C. 1974. Experiences in sod-seeding Siratro into native speargrass on granite soil near Mundubbera. Trop. Grassl. 8:128-132.

van der Kley, F. K. 1956. A simple method for the accurate estimation of daily variations in the quality and quantity of herbage consumed by rotationally grazed cattle and sheep. Neth. J. Agric. Sci. 4:197-204.

Van Soest, P. J. 1968. Techniques in forage evaluation. Proc. Arkansas Formula Feed Conf., p. 37-42.

______________. 1973. Composition and nutritive value of forages. In: M. E. Heath, D. S. Metcalfe and R. E. Barnes (ed.) Forages. The Iowa State University Press, Ames.

Vicente-Chandler, J., R. Caro-Costas and J. Figarella. 1953. The effect of two heights of cutting and three fertility levels on yield, protein content and species composition of a tropical kudzu and molassesgrass pasture. Agron. J. 45:397-400.

Villasmill, J. J., J. Atencio, J. Barcenas, A. Casanova, M. Urdaneta and D. H. Timm. 1975. Response surface designs and linear programming applied to cattle-forage-feeding systems in the tropics. In: Tropical forages in livestock production systems. Spec. Pub. No. 24. The American Society of Agronomy, Madison.

Waite, R. E. 1958. The water-soluble carbohydrates of grasses. IV. The effect of different levels of fertilizer treatment. J. Sci. Food Agric. 9:39-43.

Walker, B., and J. K. Potere. 1974. Effect of stocking rate on plant populations in tropical legume-grass pastures. Int. Grassl. Congr., Proc. 12th, 388-394.

Warmke, H. E., R. H. Freyre and M. P. Morris. 1952. Studies on palatability of some tropical legumes. Agron. J. 44:517-520.

Watkins, B. R. 1957. The effect of dung and urine and its interactions with applied nitrogen, phosphorus, and potassium on the chemical composition of pasture. J. Brit. Grassl. Soc. 12:264-277.

Watkins, J. M., and M. Lewy-van Severen. 1951. Effect of frequency and height of cutting on the yield, stand, and protein content of some forages in El Salvador. Agron. J. 43:291-296.

Watson, D. J. 1952. The physiological basis of variation in yield. Adv. Agron. 4:101-145.

Weinmann, H. 1943. Effects of defoliation intensity and fertilizer treatment on Transval Highveld. Emp. J. Exp. Agric. 11:113-124.

Wheeler, J. L. 1960. Field experiments on systems of management for mesophytic pastures. CSIRO Div. Plant Industry Rep. No. 20.

__________. 1962. Experimentation in grazing management. Herb. Abstr. 32:1-7.

__________, J. C. Burns, R. D. Mochrie and H. D. Gross. 1973. The choice of fixed or variable stocking rate in grazing experiments. Exp. Agric. 9:298-302.

Whitney, A. S. 1970. Effects of harvesting interval, height of cut, and nitrogen fertilization on the performance of Desmodium intortum mixtures in Hawaii. Int. Grassl. Congr., Proc. 11th, 632-636.

Wilkinson, P. R., and J. T. Wilson. 1959. Survival of cattle ticks in central Queensland pastures. Austr. J. Agric. Res. 10:129-143.

Wilkinson, S. R., W. E. Adams and W. A. Jackson. 1970. Chemical composition and in vitro digestibility of vertical layers of coastal vermudagrass (Cynodon dactylon L.). Agron. J. 62:39-43.

Williams, R. F. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. Ann. Bot., London, 10:41-72.

Williams, R. J., and J. R. Baker. 1968. A comparison of response surface and factorial designs in agricultural research. Rev. Mktg. Agric. Econ., Sydney, 36:165-177.

Willoughby, W. M. 1959. Limitations to animal production imposed by seasonal fluctuations in pasture and by management procedures. Austr. J. Agric. Res. 10:248-255.

Wilson, J. R., and C. W. Ford. 1971. Temperature influences on the growth, digestibility and carbohydrate composition of two tropical grasses Panicum maximum var. Trichoglume and Setaria sphacelata and two cultivars of the temperature grass Lolium perenne. Austr. J. Agric. Res. 22:563-571.

Winks, L., F. C. Lamberth, K. W. Moir and P. M. Pepper. 1974. Effect of stocking rate on the performance of steers grazing Townsville stylo-based pastures in north Queensland. Austr. J. Exp. Agric. Anim. Husb. 14:146-154.

Winter, W. H. 1975. CSIRO Div. Trop. Agron. Ann. Rep. 1974-75. p. 40.

Wishart, J., and H. G. Sanders. 1958. Principles and practice of field experimentation. Commonwealth Agricultural Bureaux, Cambridge.

Yates, J. J., M. J. Russel and I. F. Fergus. 1971. Effects and interaction of lucerne and subtropical legumes in a Sorghum almum pasture. Austr. J. Exp. Agric. Anim. Husb. 11:651-661.

Young, J. G., and F. Chippendale. 1970. Beef cattle performance on pastures on heath plains in southeast Queensland. Int. Grassl. Congr., Proc. 11th, 849-852.

BIOGRAPHICAL SKETCH

Emanuel Adilson Souza Serrão was born on March 28, 1941, in the community of Belterra, State of Pará, Brazil. His father is Valentim Silva Serrão and his mother Anísia Souza Serrão.

He completed high school at the Escola Agrotécnica "Nilo Peçanha," in Pinheiral, State of Rio, in 1961. In 1965, he received his Bachelor of Science degree in Agronomy from the Escola de Agronomia da Amazônia, in Belém, State of Pará.

In 1966, he was granted a scholarship by the Brazilian Ministry of Agriculture/USAID program to pursue graduate training at the University of Wisconsin, Madison, where, in 1968, he was awarded the Master of Science degree in Agronomy.

Upon his return to Brazil in March 1968, he began developing research programs on forage crops and pastures at the Instituto de Pesquisas Agropecuárias do Norte (IPEAN) in the humid tropical Amazon Region.

In January 1974, he began his academic program at the University of Florida for the degree of Doctor of Philosophy in Agronomy with major interest in management of forage crops and pastures, under the sponsorship of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), the official Brazilian agriculture research institution.

He is a member of the Sociedade Brasileira de Zootecnia, the American Society of Agronomy, the American Society of Range Management, the American Society of Animal Science, and Gamma Sigma Delta (Florida Chapter).

He is married to Christine Susan Moore Serrão, and they have a daughter, Leandra.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Gerald O. Mott

Gerald O. Mott, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John E. Moore

John E. Moore
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Hugh Popenoe

Hugh L. Popenoe
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Larry D. White

Larry D. White
Associate Professor of Range Ecosystem Management

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ramon C. Littell

Ramon C. Littell
Associate Professor of Statistics

This dissertation was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1976

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School